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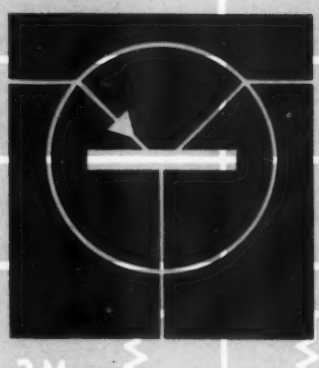

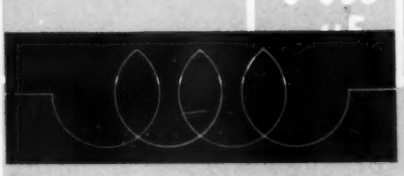

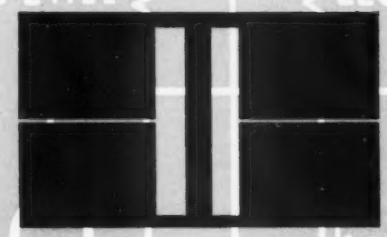

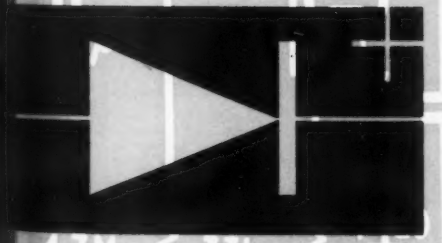

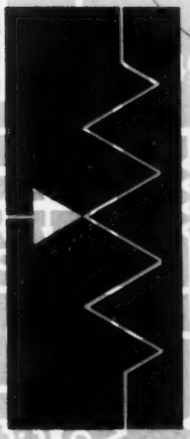

Electronics for radiation detection

. . . page 95

September 1959 monthly 3/6

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VOL 4 NO 41 SEPTEMBER 1959

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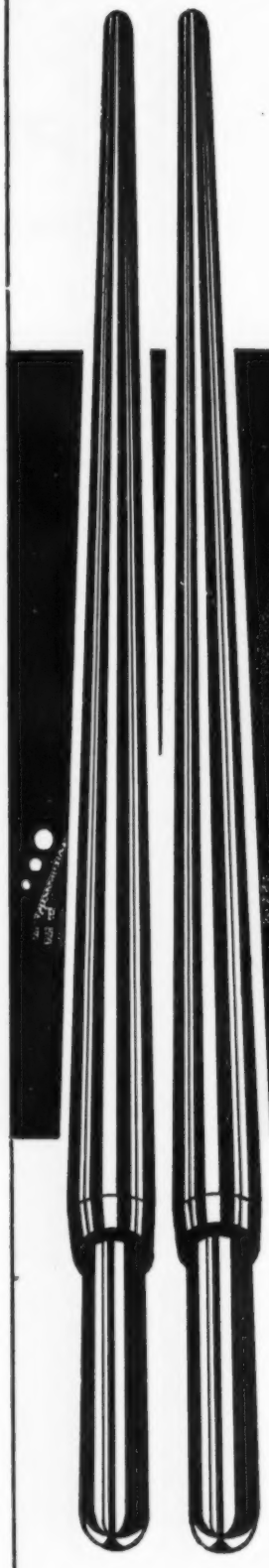

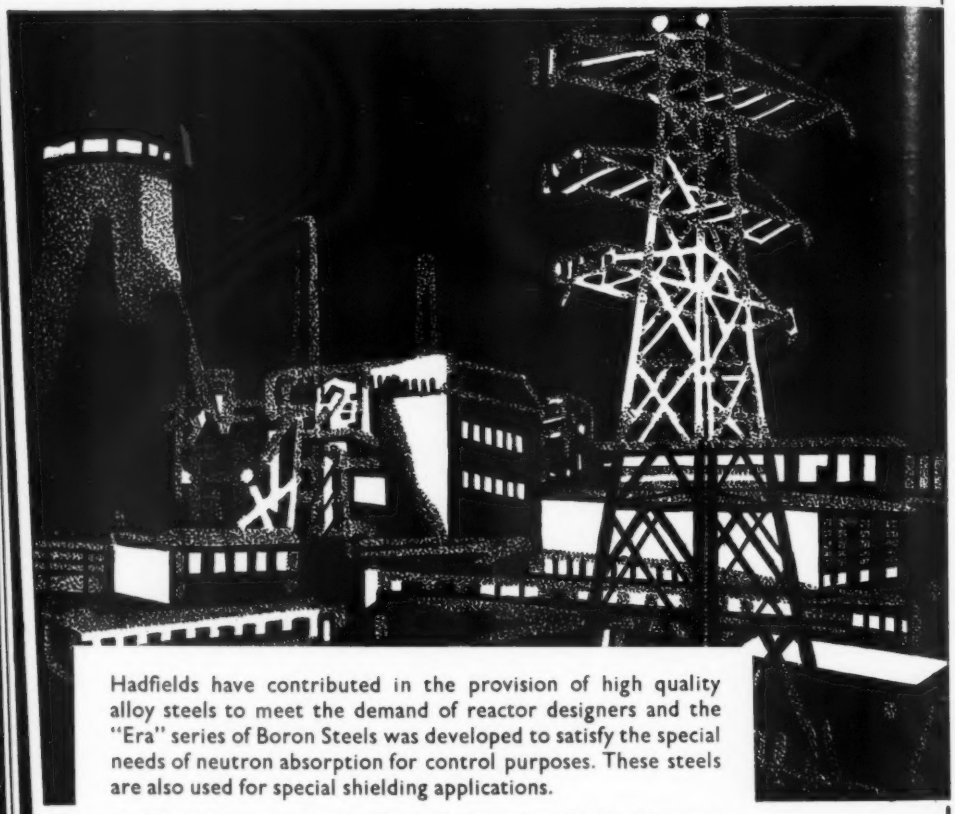

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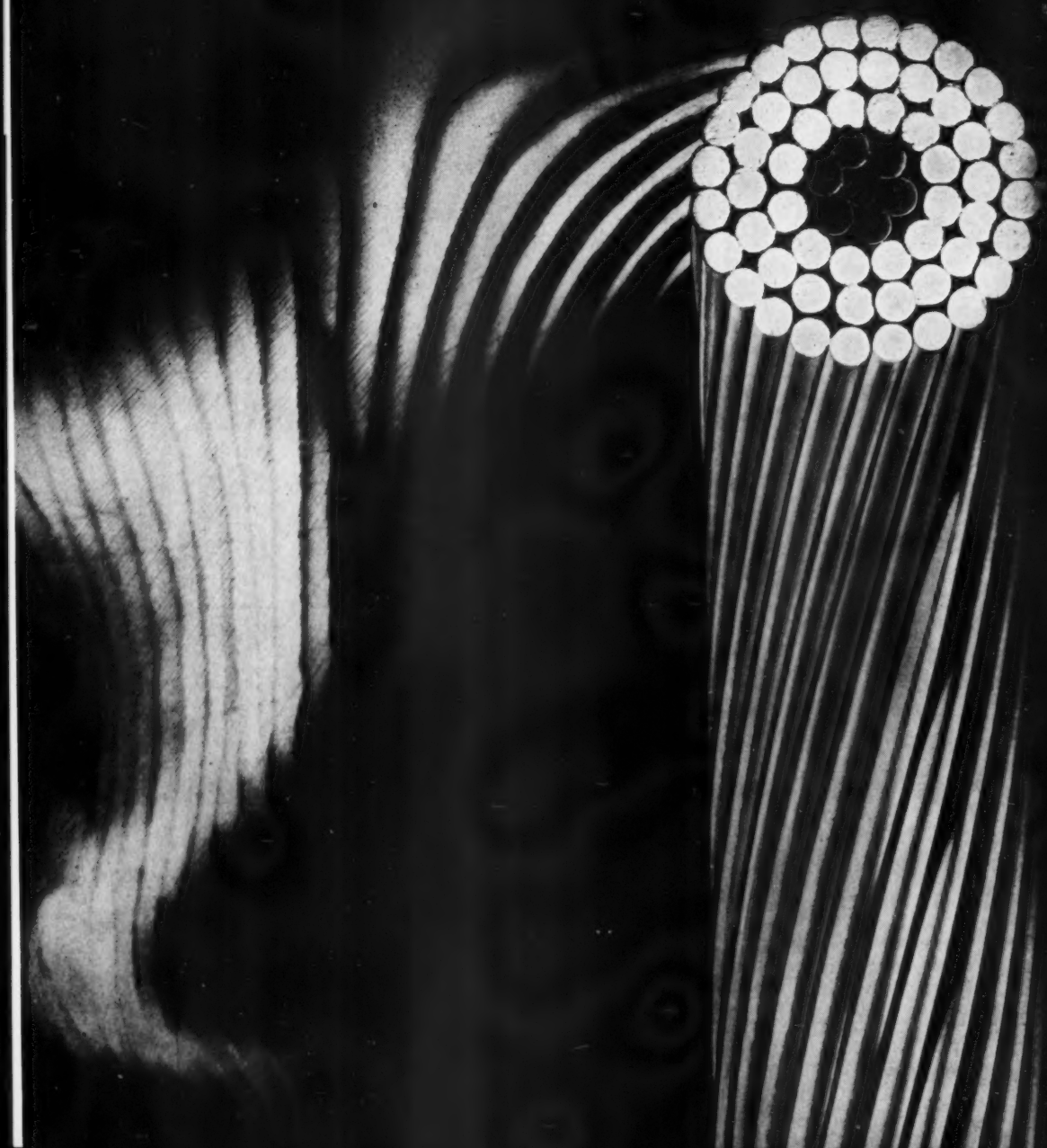


protection for the grid

The great web of overhead lines which covers this country, the thousands of miles of conductors that stretch out over factory chimneys, along the sea shores, over rivers and estuaries, sets a particularly difficult corrosion problem. Everywhere there is a tendency for the protectives to drain away down the sagging curve of the lines, leaving the sections near the insulators bare. Every day these unprotected sections are attacked by the acid fumes of industrial areas, the mist and wind-borne salt from the sea.

Here was a problem, indeed; to produce a protective which would be liquid enough to apply in manufacture, and yet on cooling would remain plastic and solid enough to resist the tendency to drain away under the heat of the summer sun.

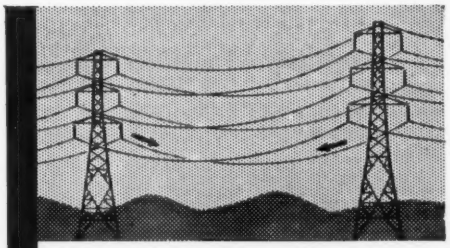
Shell spent many years examining these apparently contradictory requirements. Finally they produced Shell Ensis Compound 356. A measure of the success of their research is that 356 will add years to the life of s.c.a. conductors. Because of its unique qualities it was applied in the manufacture of the 2½ mile transmission cables spanning the estuaries of the Rivers Severn and Wye, one of the highest and longest river crossings in the world.

The research that went into 356 is characteristic of the way Shell set about doing things. It was developed at Shell's Research Centre at Thornton, and is the end product of a long line of protective greases. In its experimental form 356 was already being used by important manufacturers supplying the Central Electricity Generating Board.

The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors to produce the right protective for the job. If you and your organization have any major lubricating problems, it pays to get in touch with Shell.

The Research Story

Special tests had to be developed to determine whether each of the many formulations examined would liquefy easily at critical temperatures and re-solidify without separation or change. At the same time the resistance to drainage at temperatures likely to be reached in summer had to be assessed. Steel plates dipped under controlled time and temperature conditions in the liquefied protective were held in temperature controlled ovens for 24 hours, the weight of material drained was then measured. Formula after formula was tried and rejected, until one which gave a negligible drainage rate was finally arrived at.



The arrows indicate that conventional lubricants flow towards the sag point. This leaves the areas nearer the pylons unprotected.

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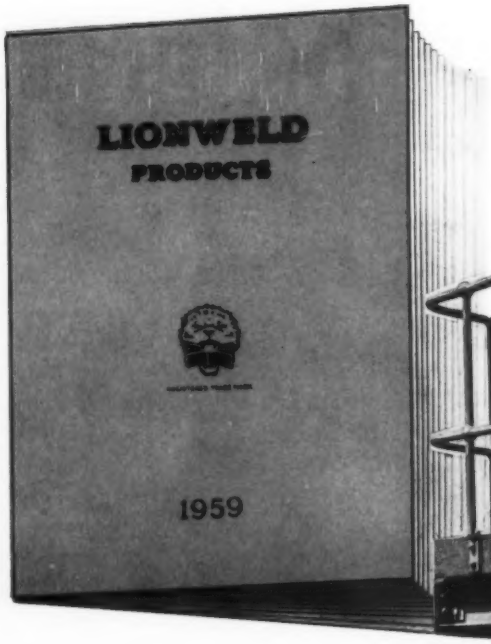

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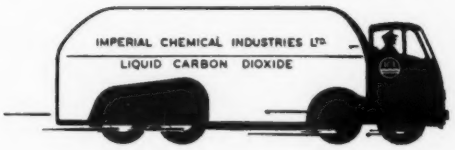

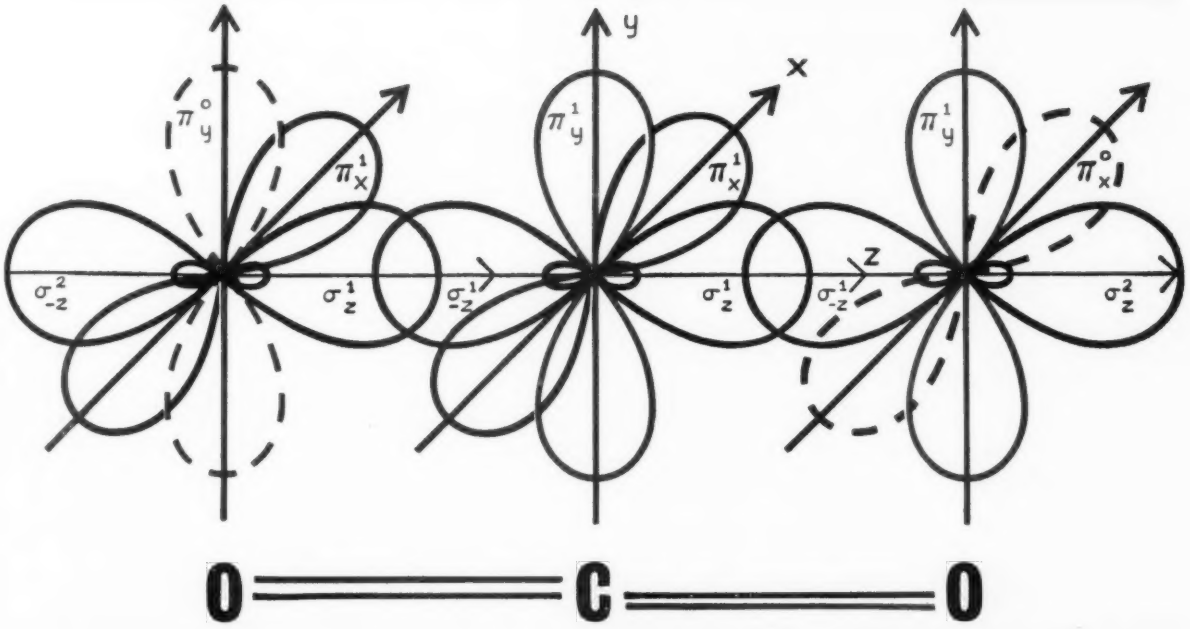

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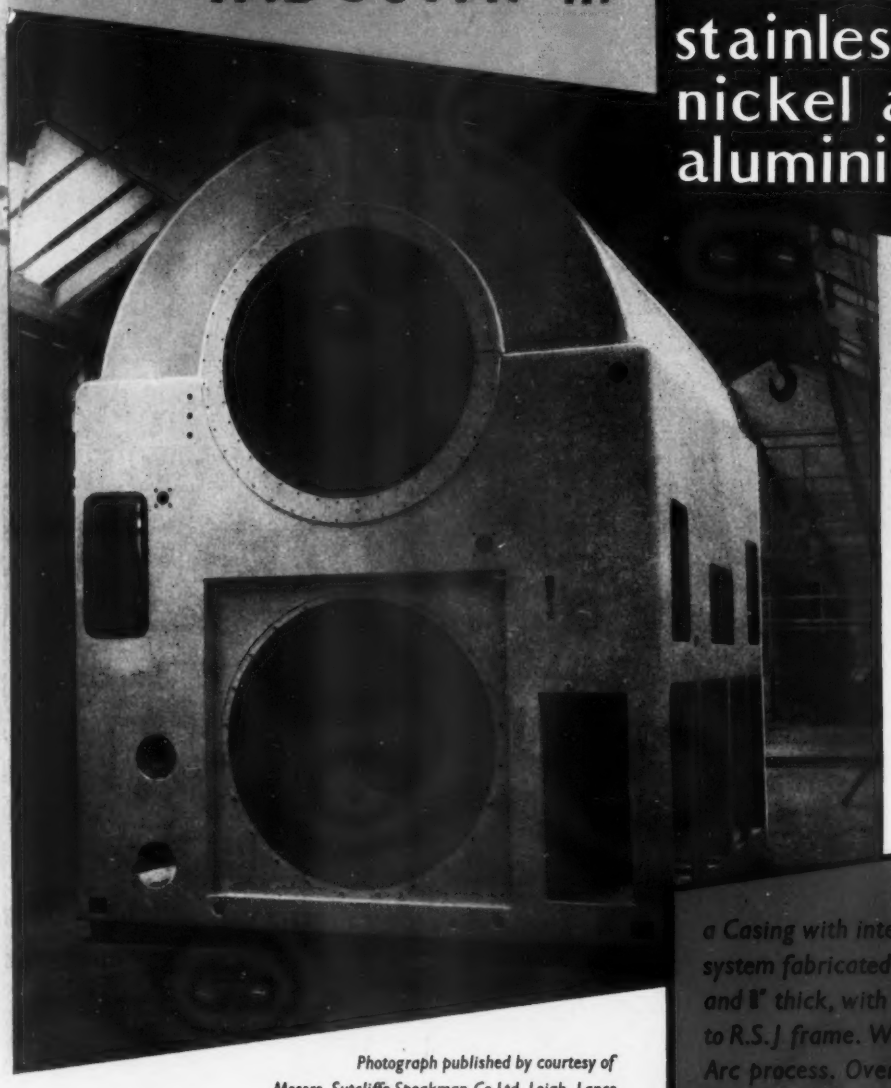

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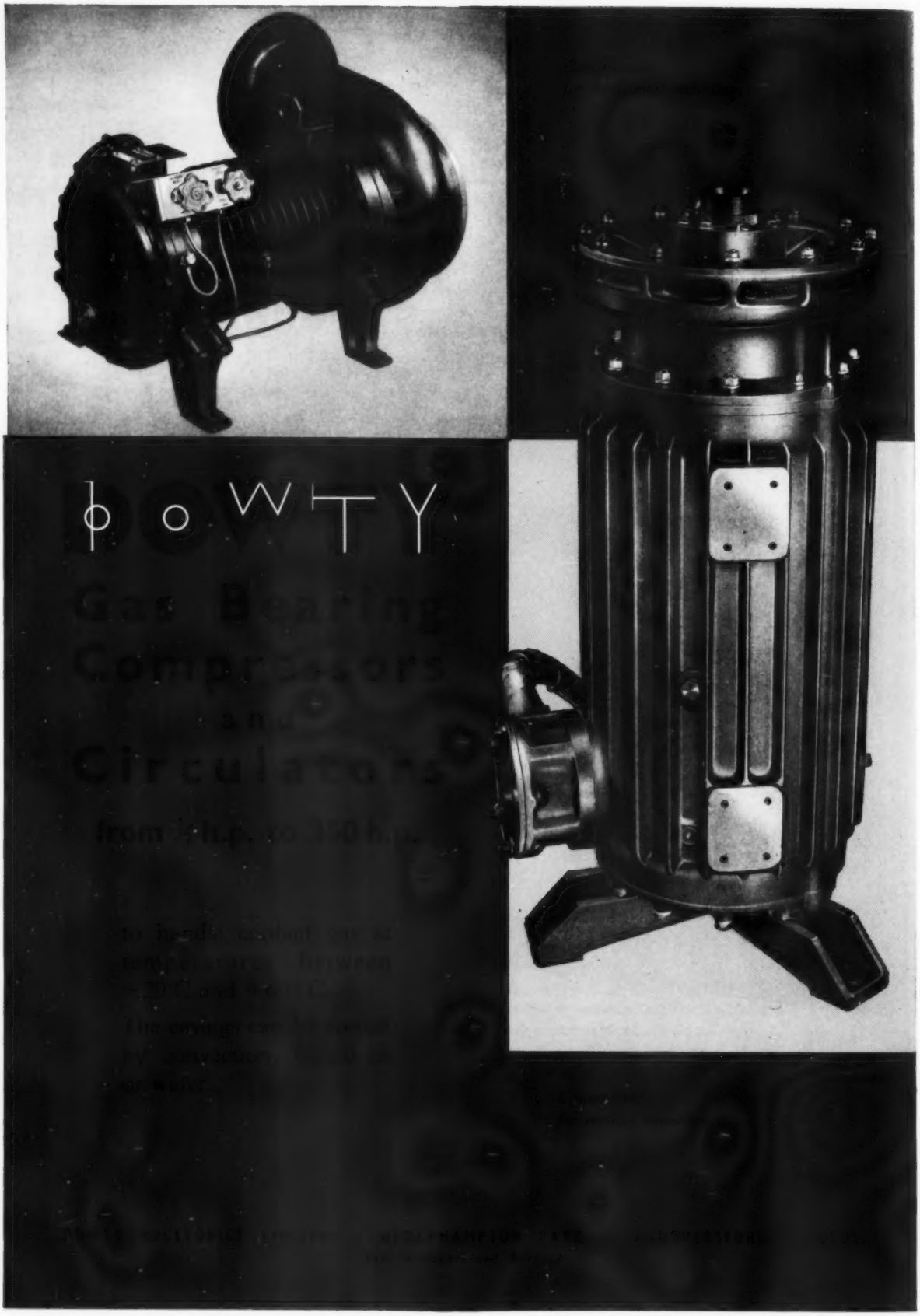
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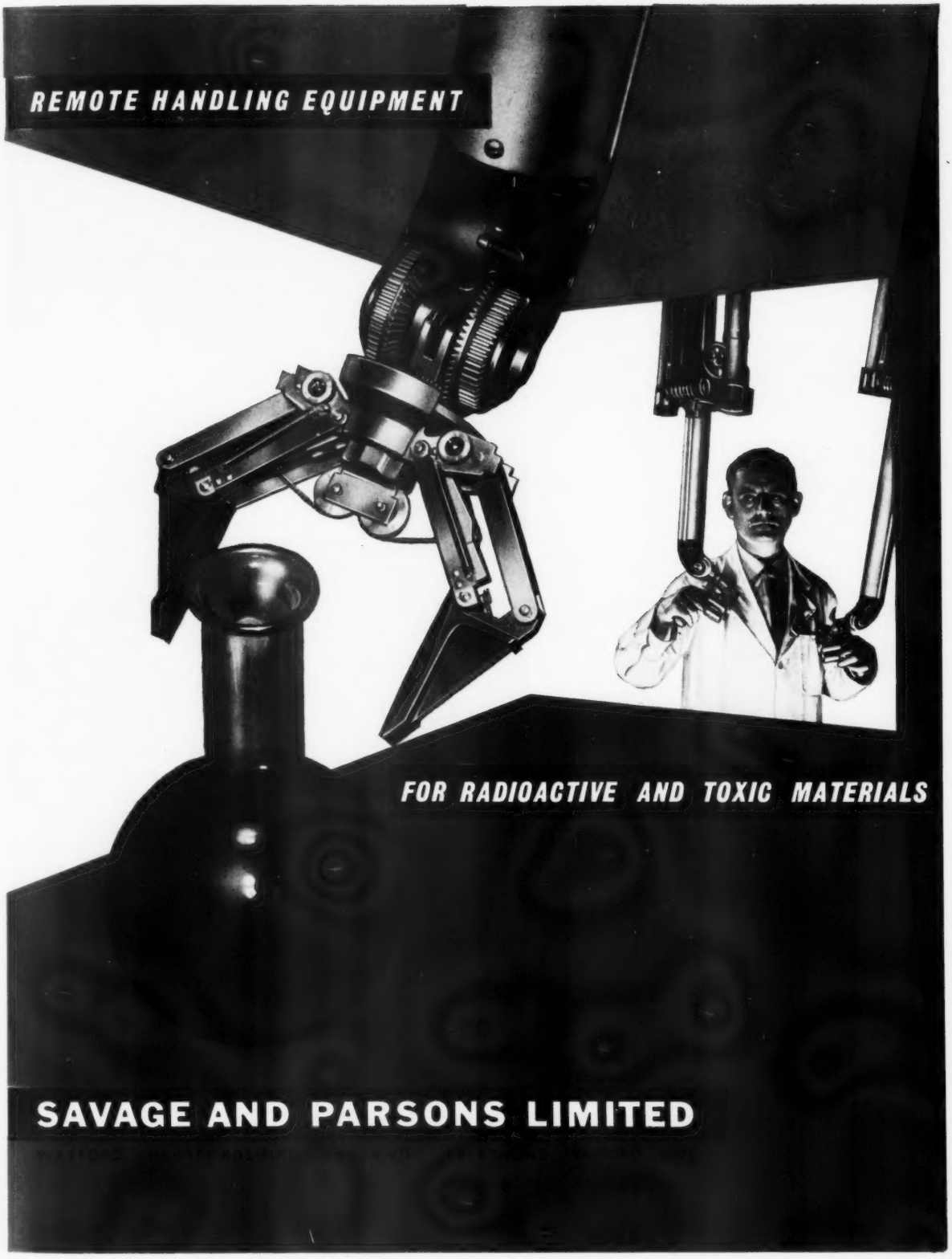
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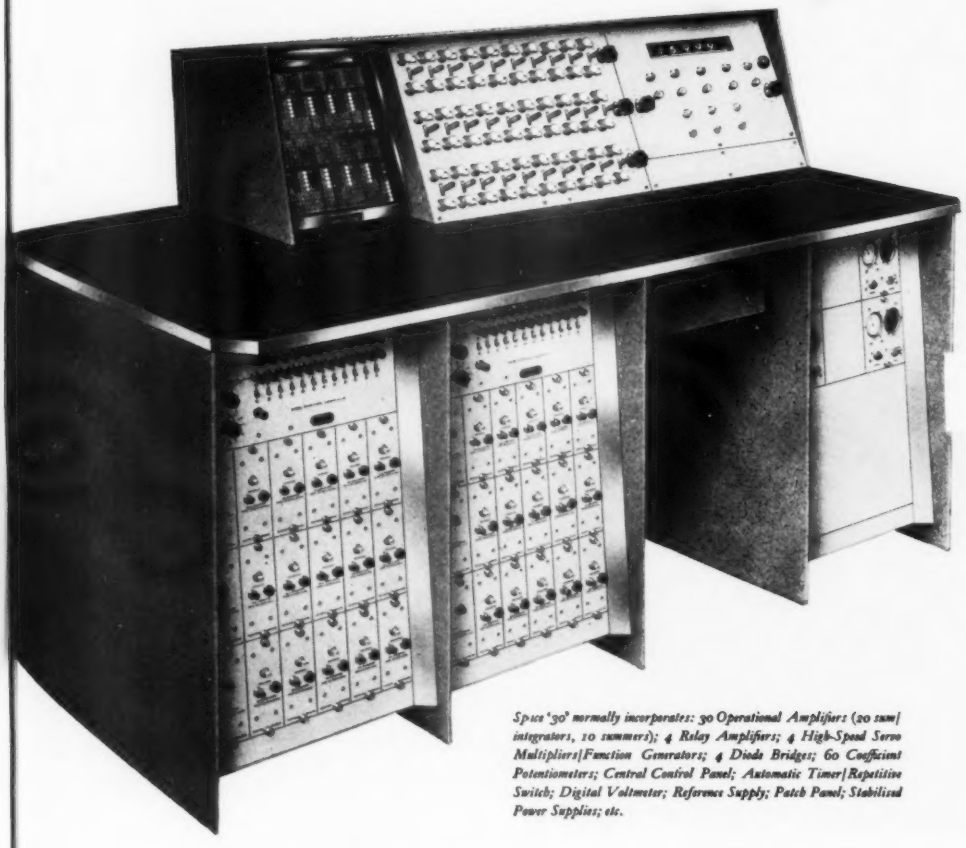

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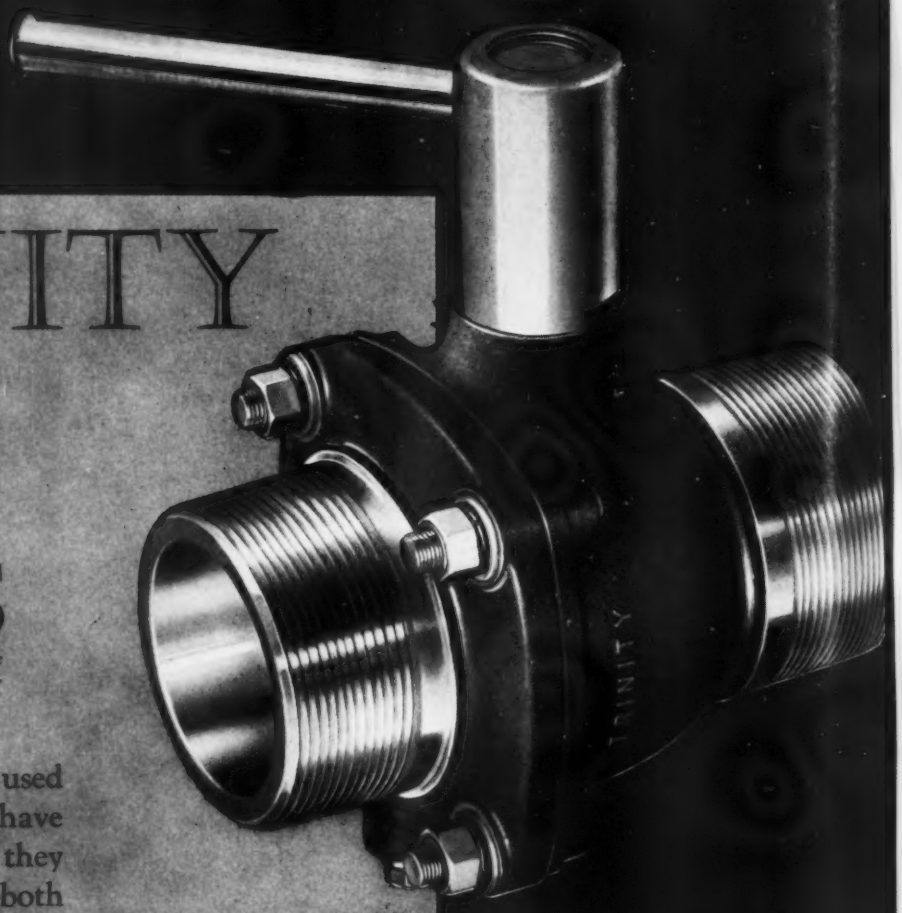

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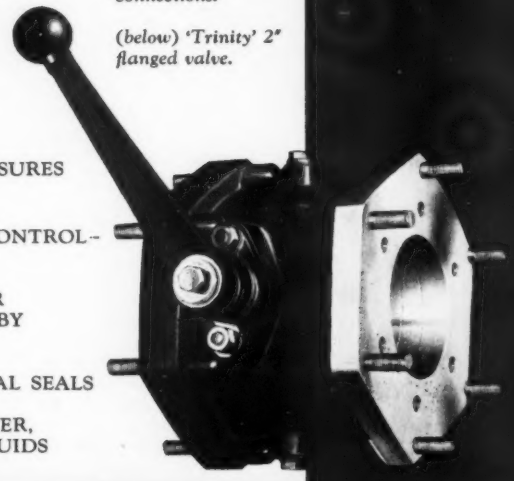

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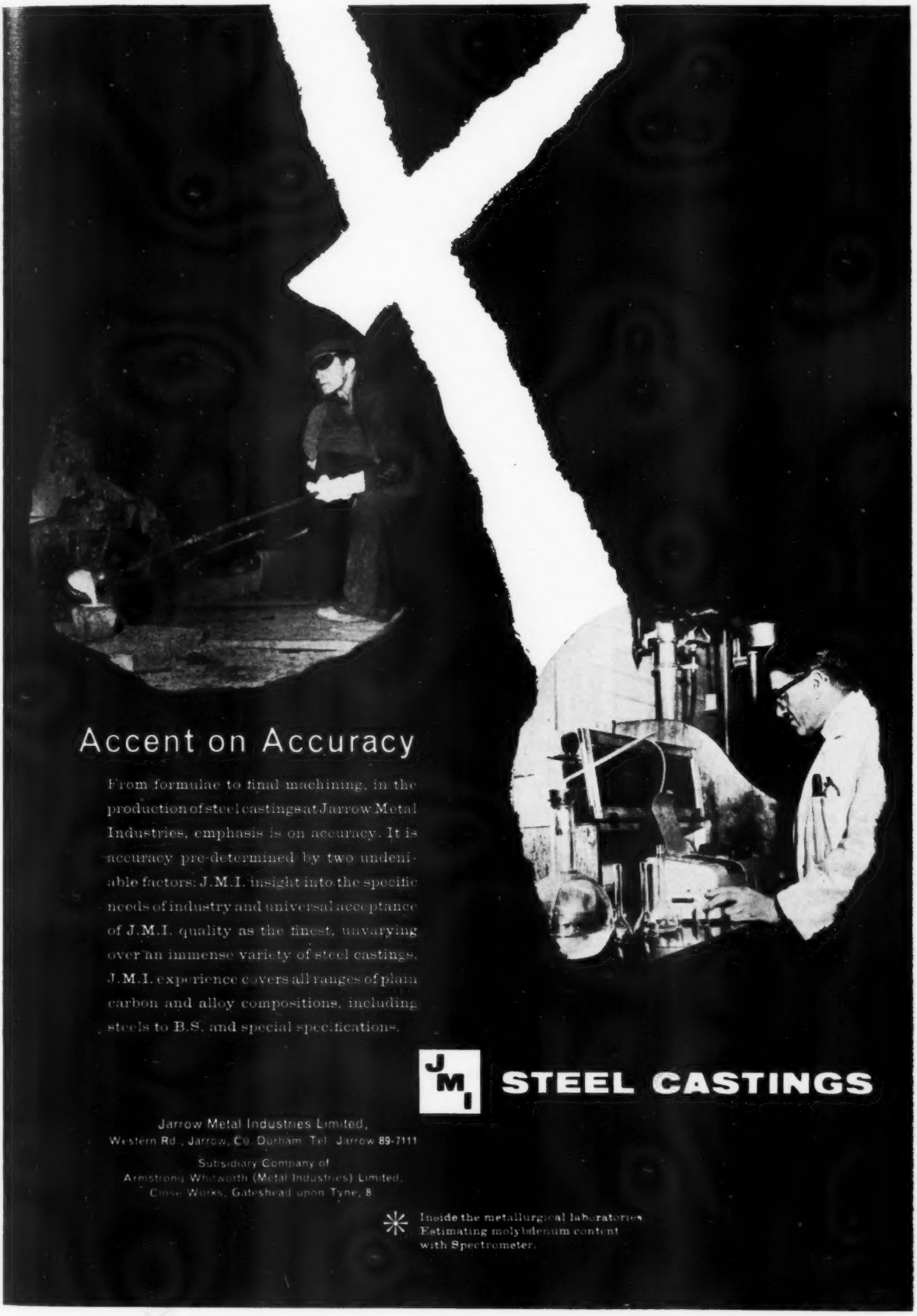

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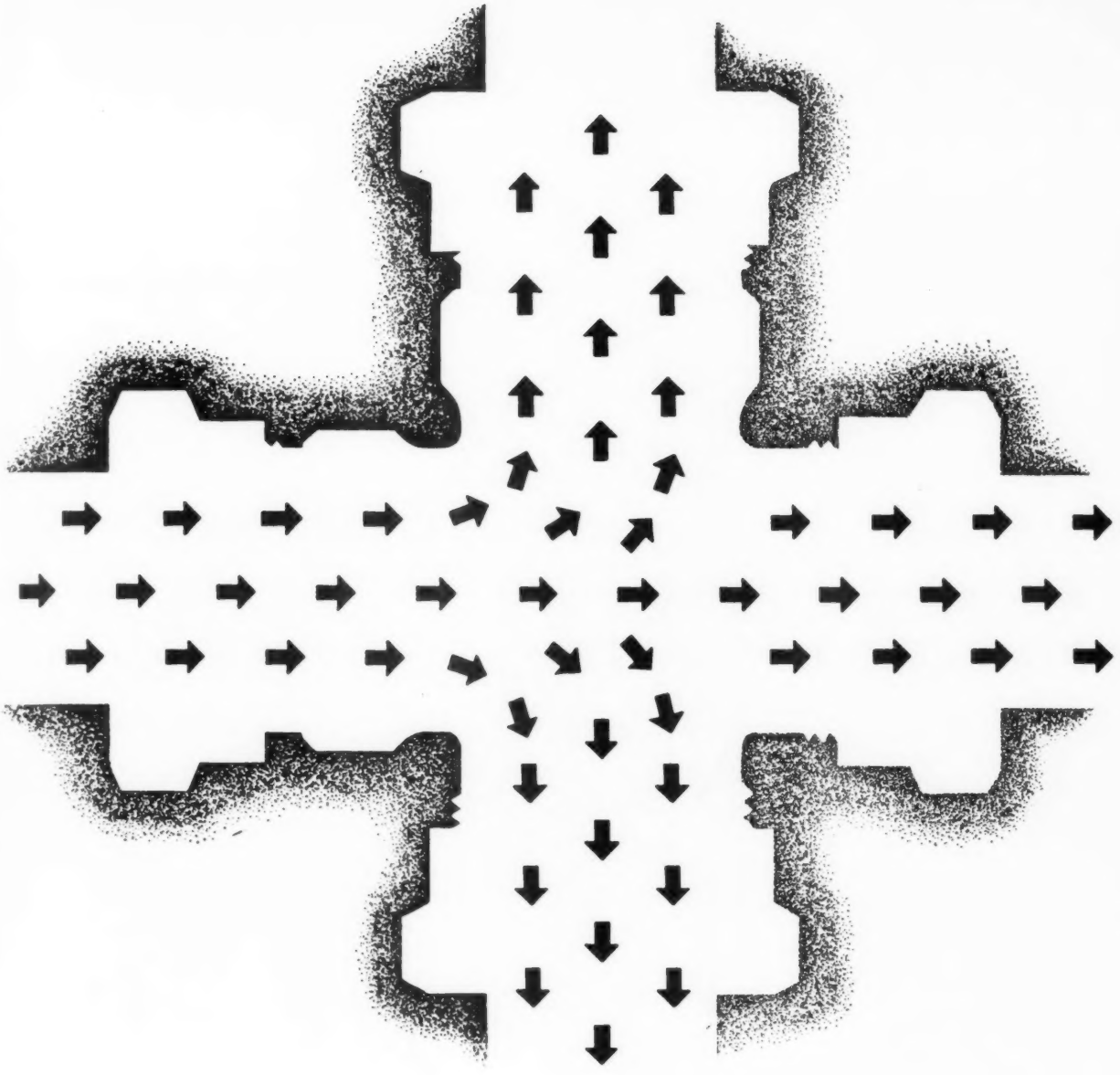

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ERMETO HIGH PRESSURE COUPLINGS are specified by many leading manufacturers, because they are the most reliable fittings on the market for every high pressure installation. Our catalogue illustrating the full range of standard fittings will be sent to you on request.

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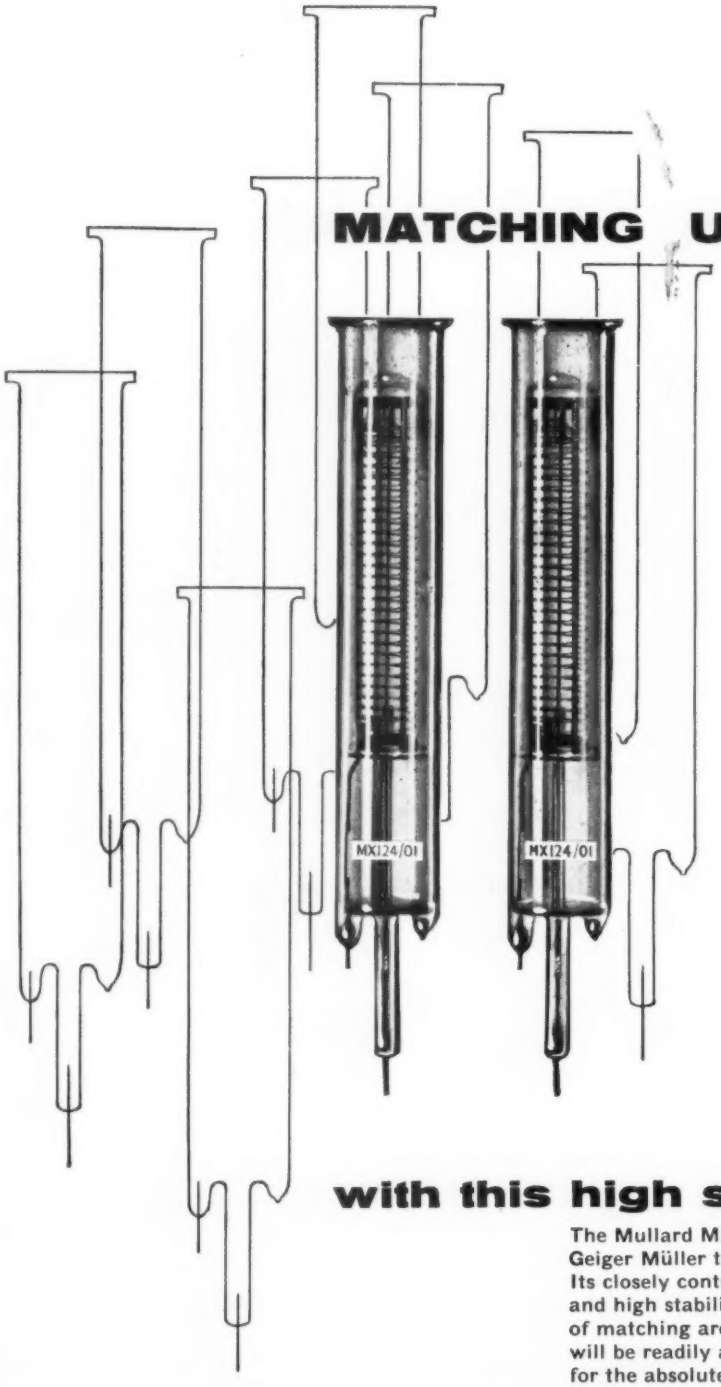

with this high stability GM tube

The Mullard MX124/01 is a halogen quenched Geiger Müller tube designed for liquid sampling. Its closely controlled operating characteristics and high stability means that the problems of matching are eliminated—an advantage that will be readily appreciated by those using G.M. Tubes for the absolute assay of radioactive solutions and the measurement of standard sources. Write now for details of this tube and others in the Mullard range.

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MULLARD LIMITED, X-RAY DIVISION, NEW ROAD, MITCHAM JUNCTION, SURREY. Telephone: MITcham 3471
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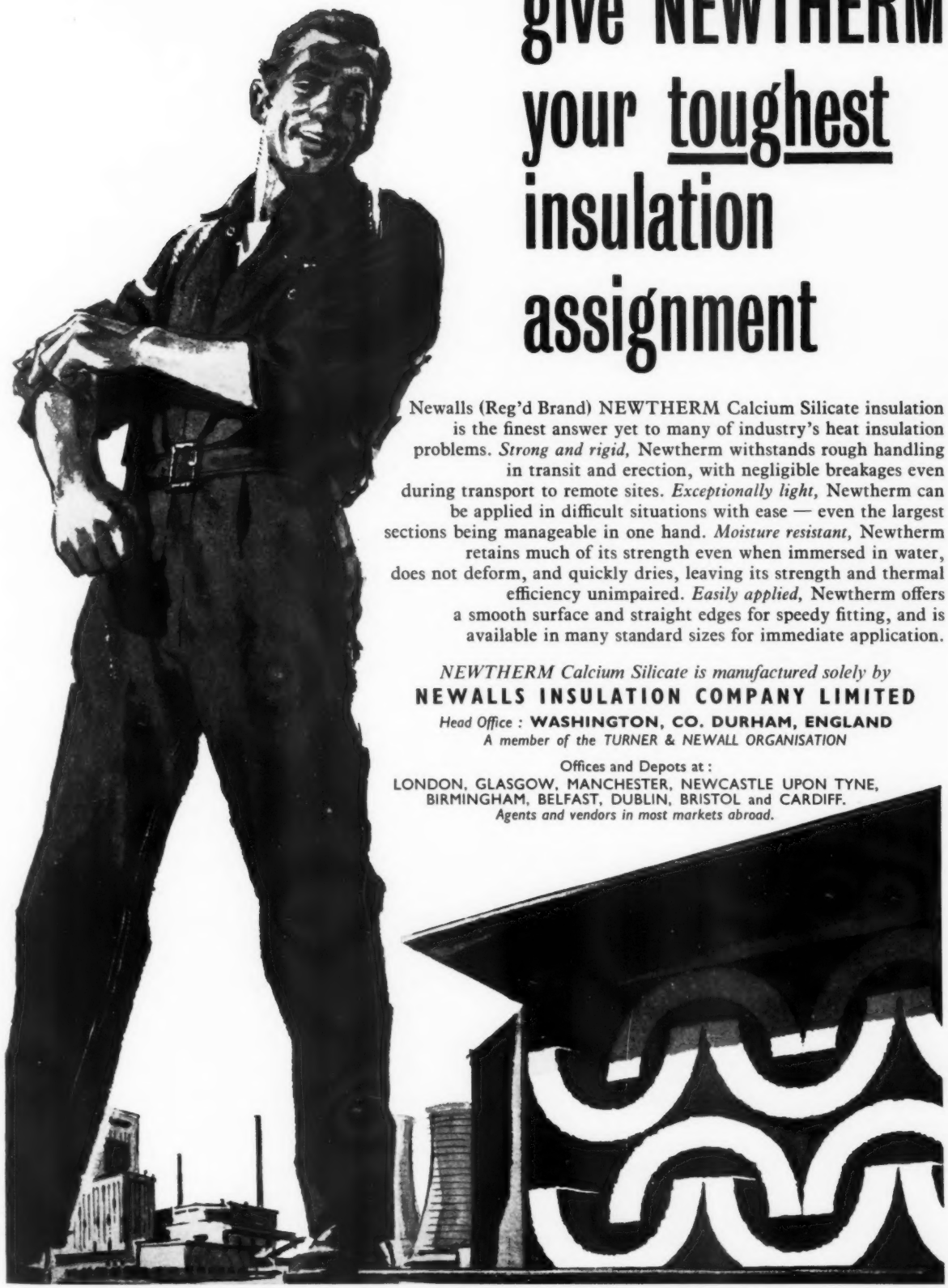

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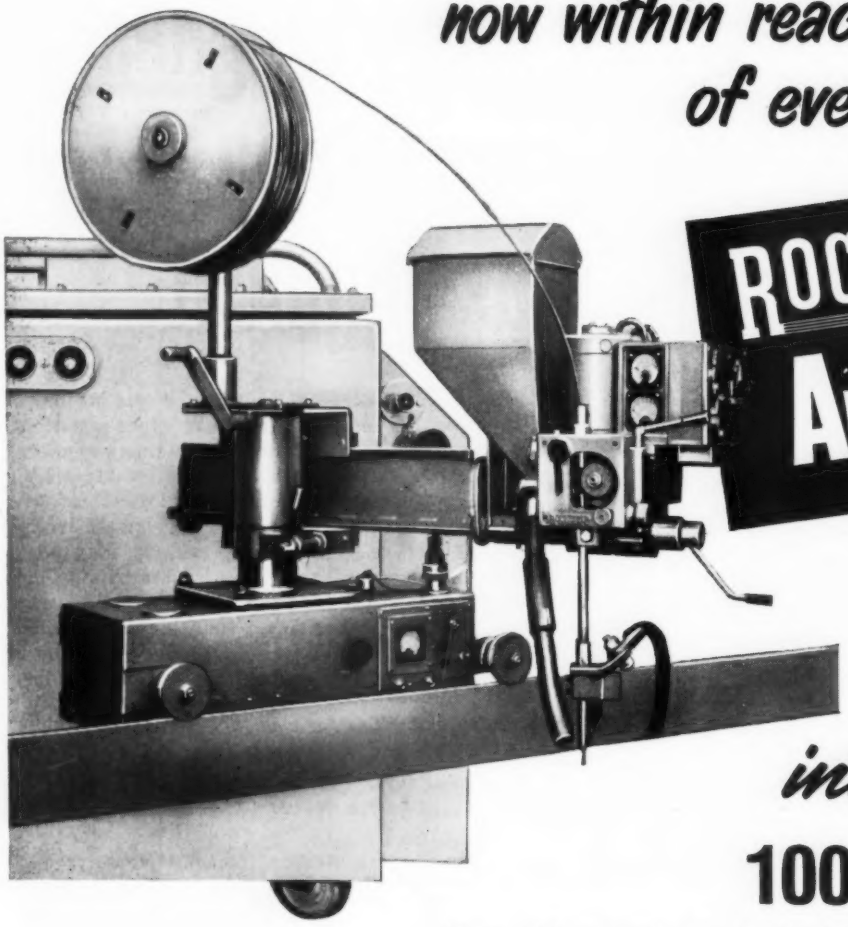

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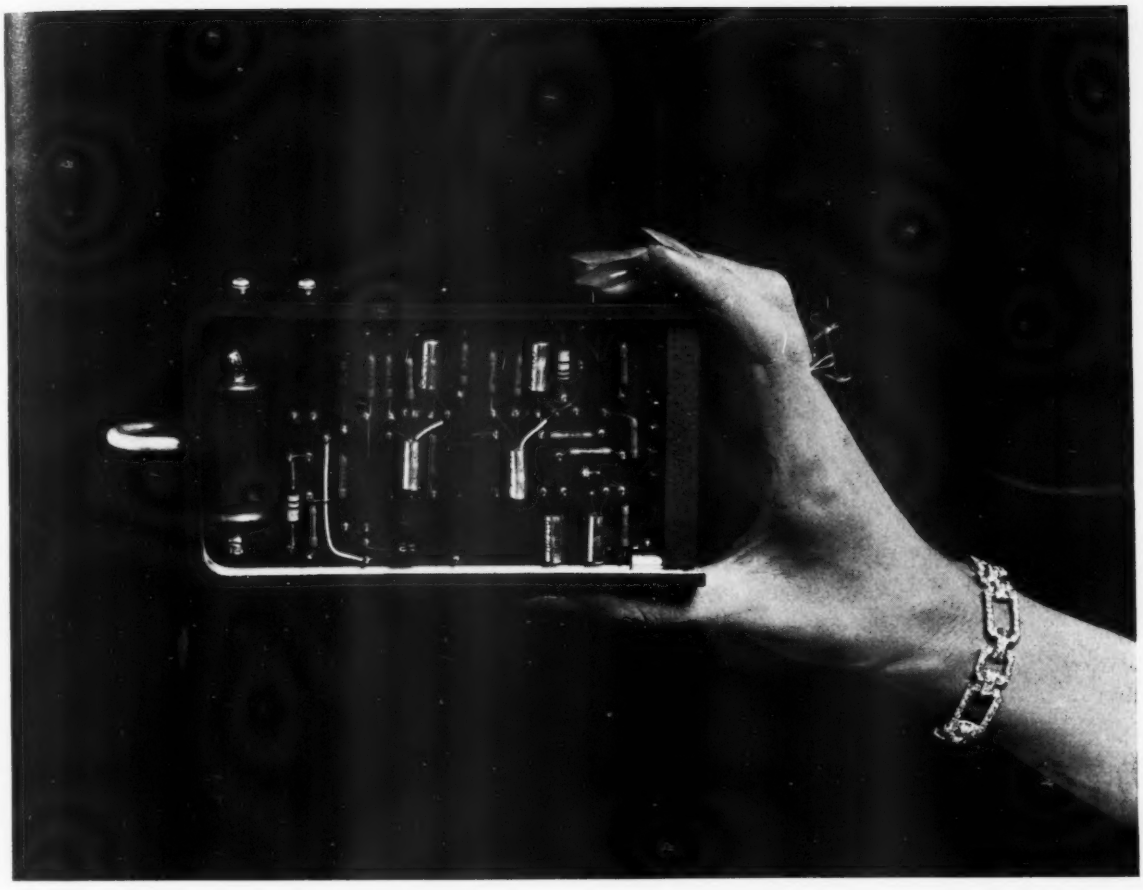

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This is our first announcement of the equipment on view at our exhibition in London on September 28, 29, 30.

Come and see it

Other features in the exhibition will be: Process control instruments, health monitoring equipment, reactor simulators and control mechanisms.

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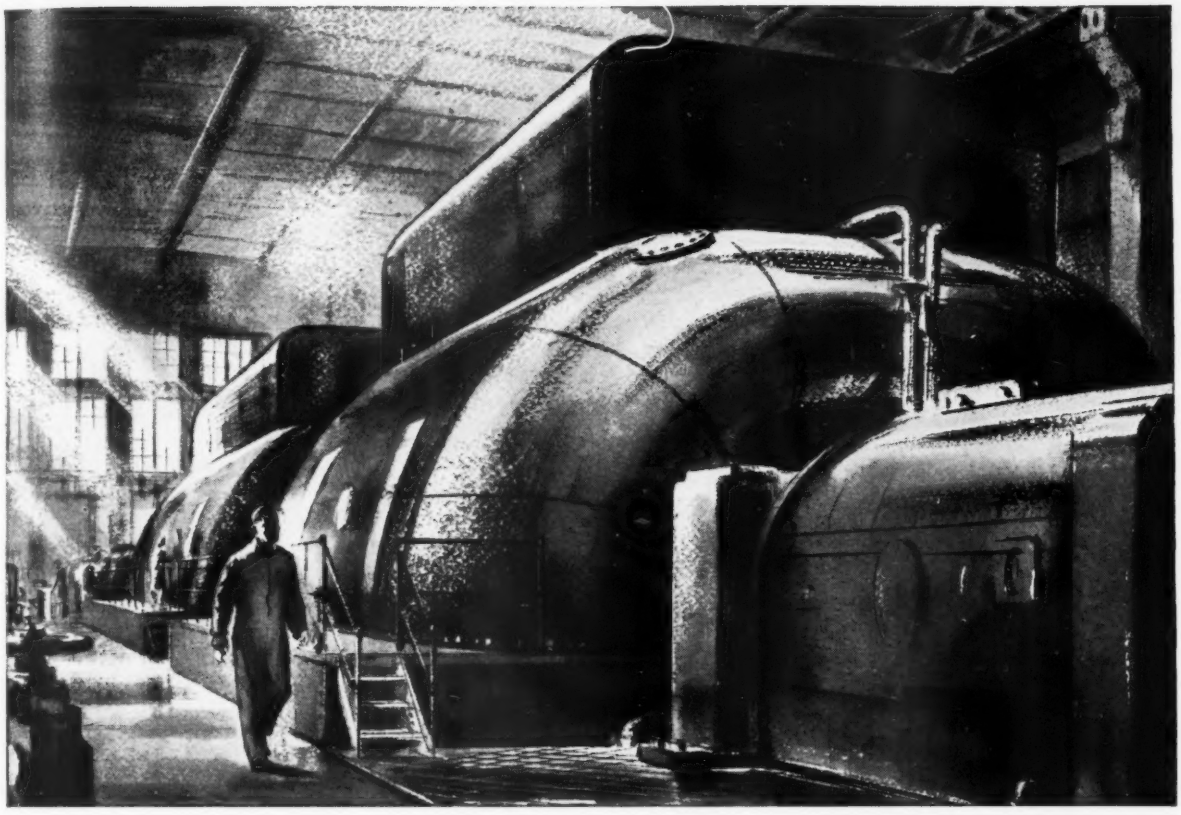
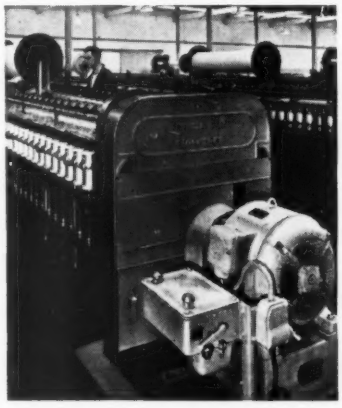


The world's largest Generators will help to fill the demand for still more power

Progress in the development of nuclear energy for generating electricity is still making front-page news —and rightly so. Spectacular advances are continually being made. Less publicised, though in their own field no less outstanding, are recent developments in the design of "conventional" generating plant. The turbo-alternator illustrated, for instance, is a 550,000 kilowatt unit—twice the capacity of the next largest generator now on order for the Central Electricity Generating Board. This machine has been designed for the projected new power station at Thorpe Marsh. For Blythe 'B', another new station, 275,000 kilowatt in-line units are on order. These sets will be served by unit boilers and will operate at steam conditions of 2350 lb. per sq. in. and 1050°F, with reheat to 1000°F.

Nuclear power stations will play an increasingly important part in meeting the doubled demand for electricity forecast for the next ten years. Construction work is progressing rapidly at the sites of the Board's first three nuclear power stations, at Bradwell, Berkeley and Hinkley Point. The aggregate capacity of these stations will be not less than 1,100,000 kilowatts; and by 1966/7 some 5 to 6 million kilowatts of nuclear-generated electric power will be available.



Though these are projects which will not be completed for some time, the work of the Central Electricity Generating Board is playing an important part in today's fight against inflation. Power stations are being built now at an overall cost no greater than in 1948—£50 per kilowatt installed. And, although the output capacity of the industry has doubled since 1948, the increase in manpower is only about one-third.

By providing today for the power we shall need in years to come, the Central Electricity Generating Board is building a secure foundation for our future prosperity.

THE CENTRAL ELECTRICITY GENERATING BOARD

CEGB

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Altro safety treads made from I.C.I. 'Corvic' used on factory stairs by the Ford Motor Company Ltd.

When stairs are treaded with p.v.c. for safety

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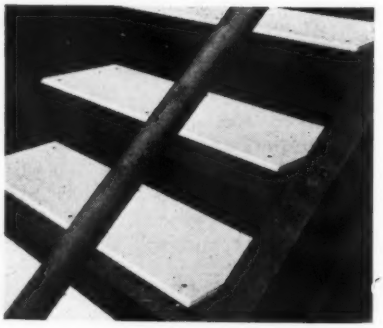
One of the many invaluable uses to which 'Corvic' is put is in the manufacture of safety treads for stairs. Factory stairs at the Ford Motor Co. Ltd., have Altro safety treads made from 'Corvic' by Welwyn Plastics (1955) Ltd. for the Adamite Co. Ltd.



'CORVIC'

'Corvic' is the registered trade mark for the p.v.c. polymers manufactured by I.C.I.

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P.C. 20

Hundreds of cutting teeth...

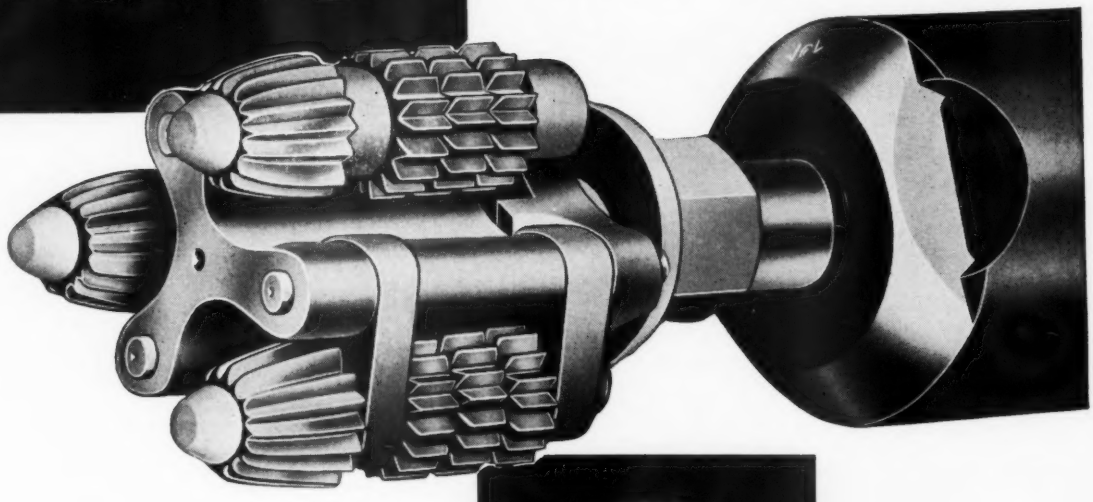
remove the toughest deposit

on any tube cleaning job!

In each swinging arm the long cutting surface of several cutters working together, comprising hundreds of sharp teeth ensure removal of the toughest deposits in straight or curved tubes.

Note, in the diagram, the wide swing of the arms of the Lagonda swing-frame head—wider than in any other swing-frame head—giving plenty of latitude for any possible variation in the I.D. of the tube.

Of course a head like this takes a lot of drive to get the best out of it. This is where the powerful Lagonda motors come in, with double ball thrust bearings and full lubrication that let practically all the power through to the cutter head. The full range of Lagonda tube cleaners caters for all types of deposits in tubes straight or curved, from ½" dia. upwards. Write for catalogue Y-48.



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TUBE CLEANERS

made by Consolidated Pneumatic

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CP.182

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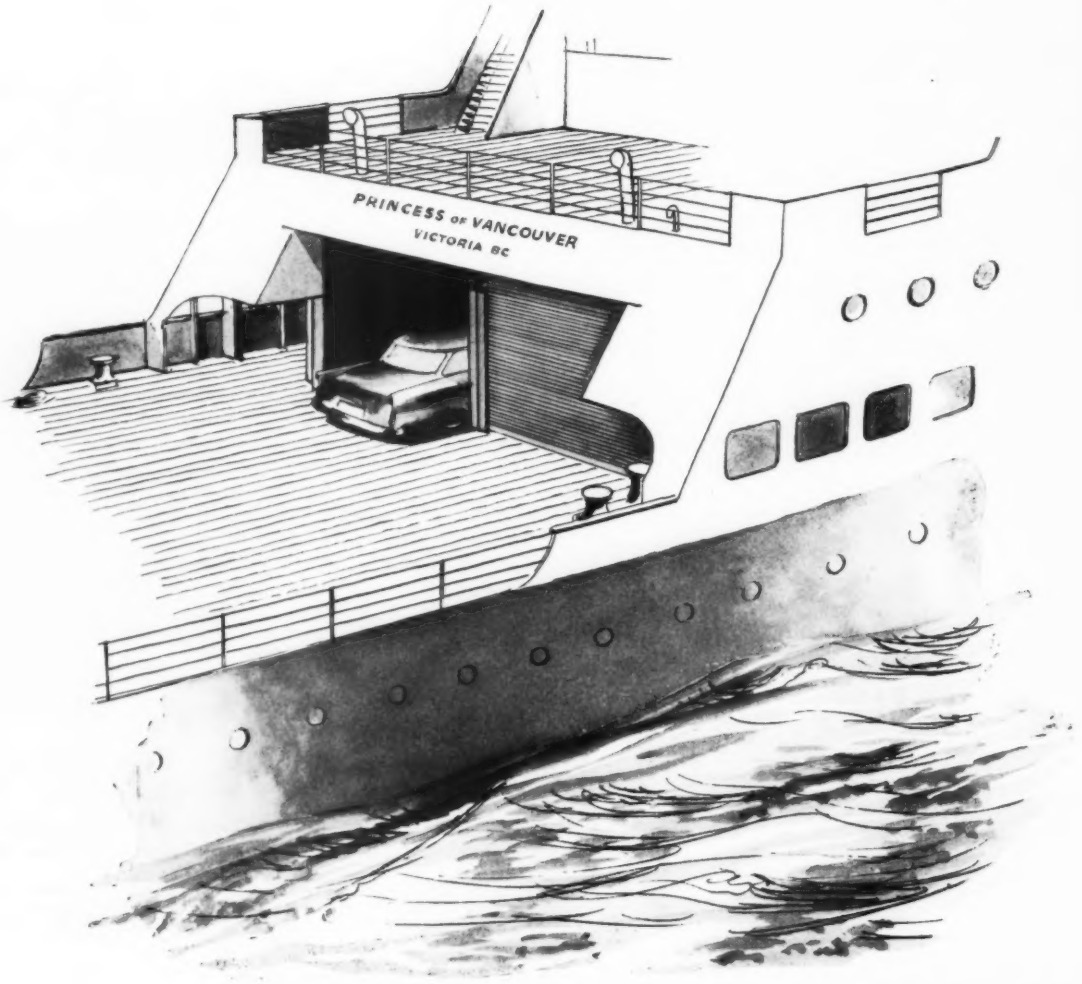
The last car rolls aboard . . . . . down come the huge shutters, and another trip begins for the "Princess of Vancouver." Brady Steel Rolling Doors are suitable for any size or kind of opening. They are designed for strength and trouble-free operation which guarantee a hundred per cent performance even in the most rigorous conditions and justify absolute confidence in their security. Hand or power operated, they are available singly or in series. Send for illustrated leaflet S/45/SS353



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"Muraflux A" is the first of a new range of Murex granular fluxes for submerged-arc welding. It has been specially developed for the welding of mild steel by all machines using A.C. or D.C. for submerged-arc welding.

The flux may be used with ordinary filler wires but is specially recommended for use with "Murawire W1" or "Murawire W2" supplied by Murex. When used with these wires, "Muraflux A" produces welds of high radiographic standard suitable for Class 1 work, and the flux has been granted approval by Lloyd's Register of Shipping and is accepted by the Ministry of Transport.

"Muraflux A" is suitable for either the single pass or multi-pass welding of various joints in mild steel as well as plug welds and the building up of worn mild steel parts. Good penetration can be obtained and unfused flux can be re-covered for further use.

"Muraflux S.1" granular flux for the submerged-arc welding of stainless steel is also available with the appropriate Murex S.W.1 and S.W.2 filler wires.

MUREX

A complete service for automatic welding

MUREX WELDING PROCESSES LTD. WALTHAM CROSS, HERTS.

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T.32

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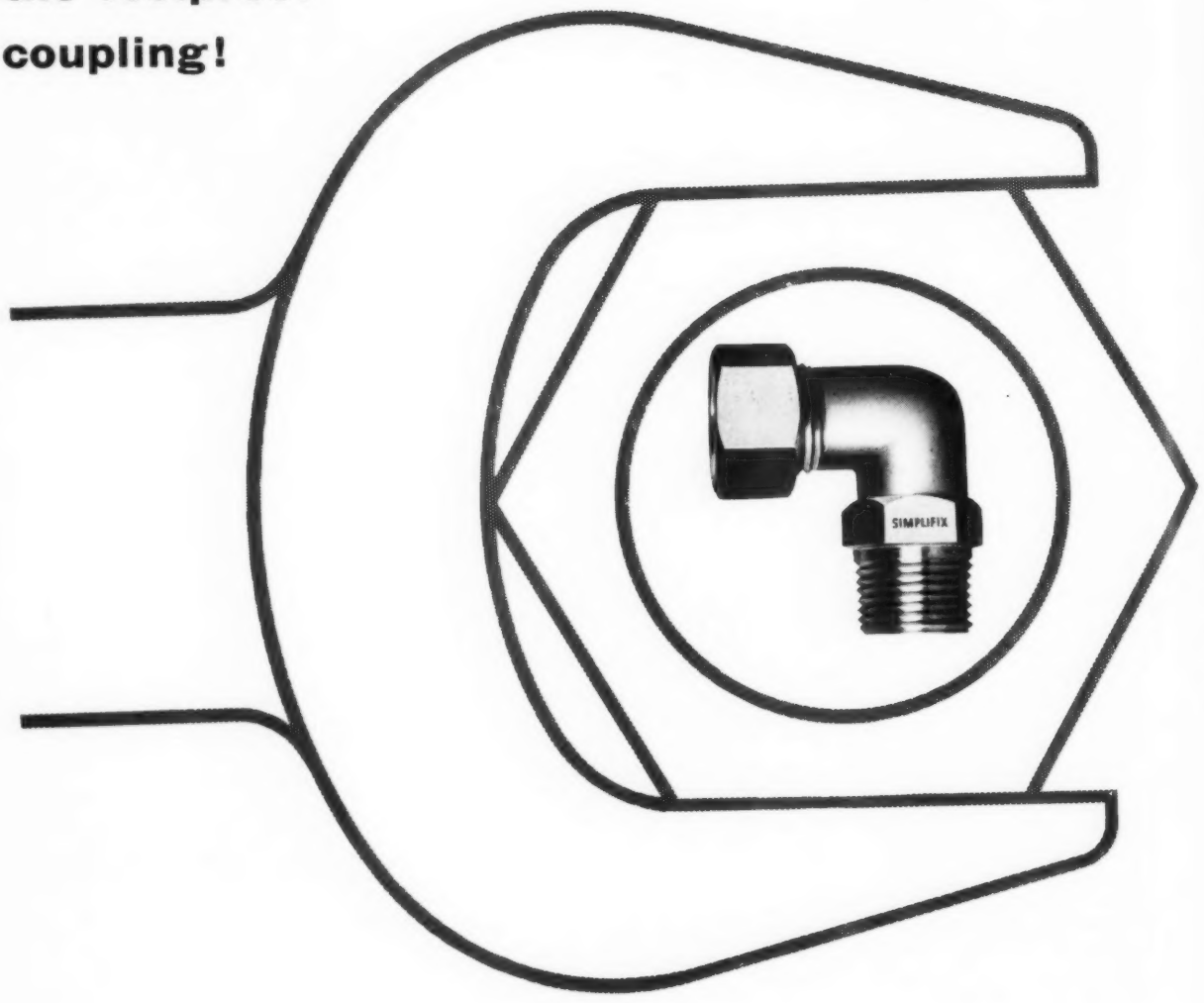
So surely SIMPLIFIX

the foolproof

coupling!



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All that is required is tightening with a spanner—
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up to 2in. o.d. In a wide range of interchangeable standard fittings.
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the
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is being
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Butterfield

AS FABRICATORS to the United Kingdom Atomic Energy Authority Butterfields have supplied or are now at work on plant for the following undertakings:
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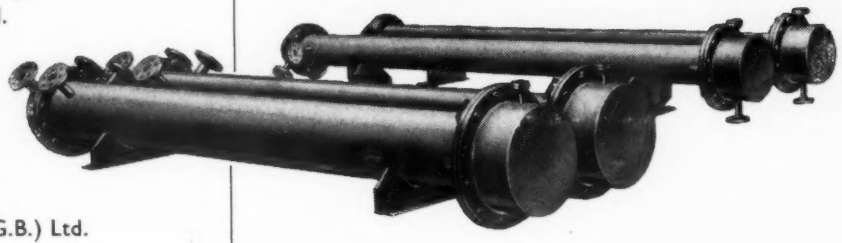

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With Safetread's welded construction, nothing can work loose or cause chattering through vibration—its design enables maximum light and air penetration and yet the danger of tools or other similar objects falling through is reduced to an absolute minimum.

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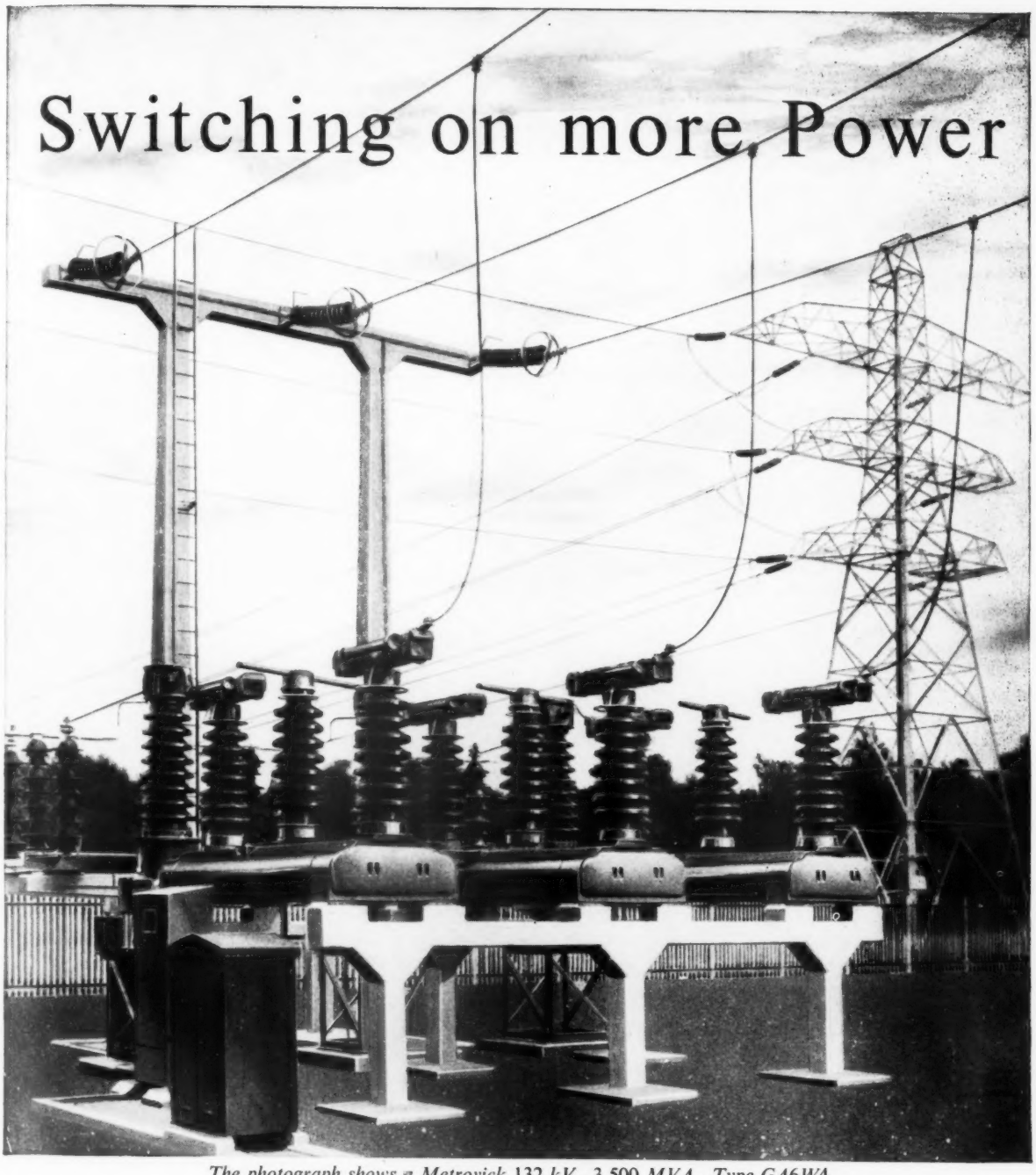

The photograph shows a Metrovick 132 kV., 3,500 MVA., Type GA6W4 Air-Blast Circuit Breaker installed in a British substation

This type of breaker is in extensive use on the British grid system, and has been selected to control the output of Scotland's first Nuclear Power Station at Hunterston. Overseas, 132kV., 5000-MVA., Type GA6W4 breakers will be installed in seven new sub-stations in the Greater Buenos Aires area of Argentina.

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SWITCHGEAR DIVISION
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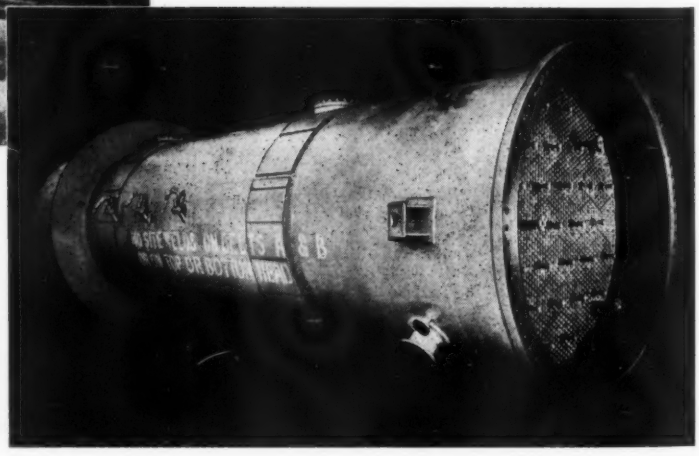
Harvey engineers are always available to discuss your fabrication problems, and to advise how we can best help you.

Left: A mild steel jacketed Autoclave to Class 1 construction with electrically driven stirring gear.

Below: This Ethylene Oxide Reactor weighs 135 tons, is 9 ft. 6 ins. in diameter and contains over 15 miles of 1¾ in. dia. catalyst tube.



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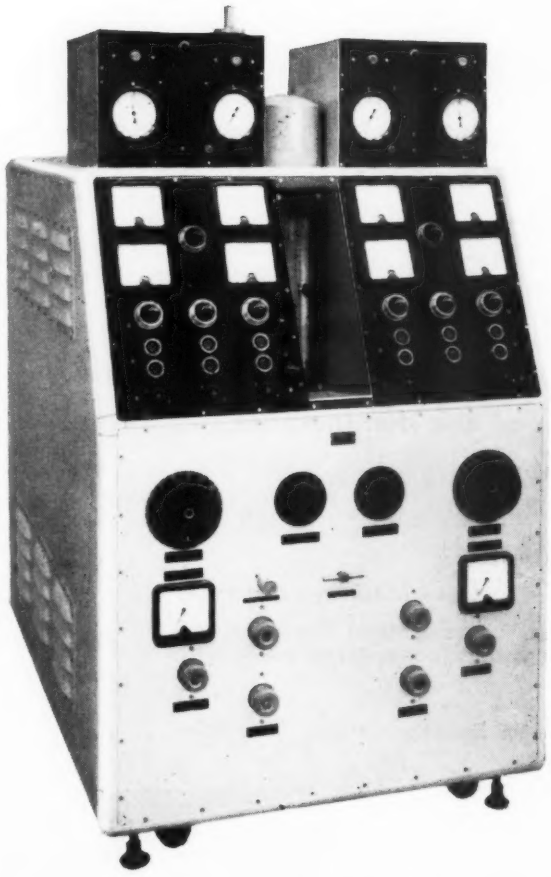

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The plant comprises the following sections:

Coagulation and Settlement — Filtration — Cation Exchange — Weakly basic Anion Exchange — Degassing — Mixed Bed Ion Exchange.

2 VEITSILUOTO O/Y, Finland

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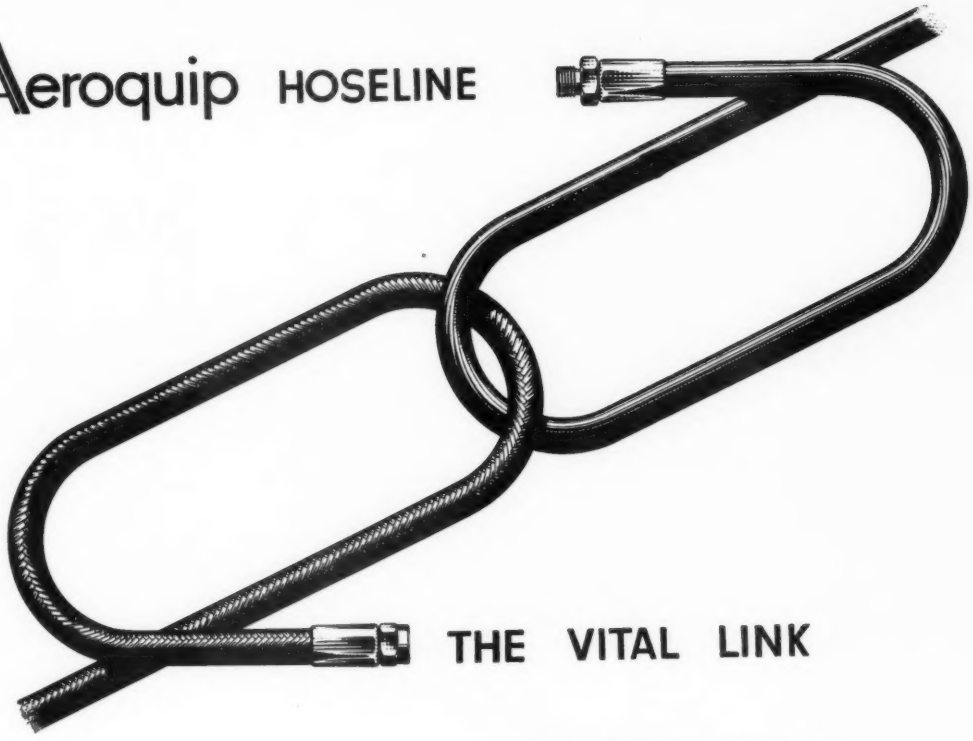
Aeroquip HOSELINE



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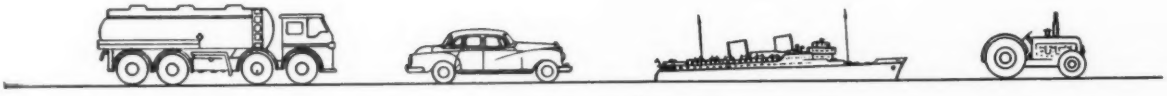

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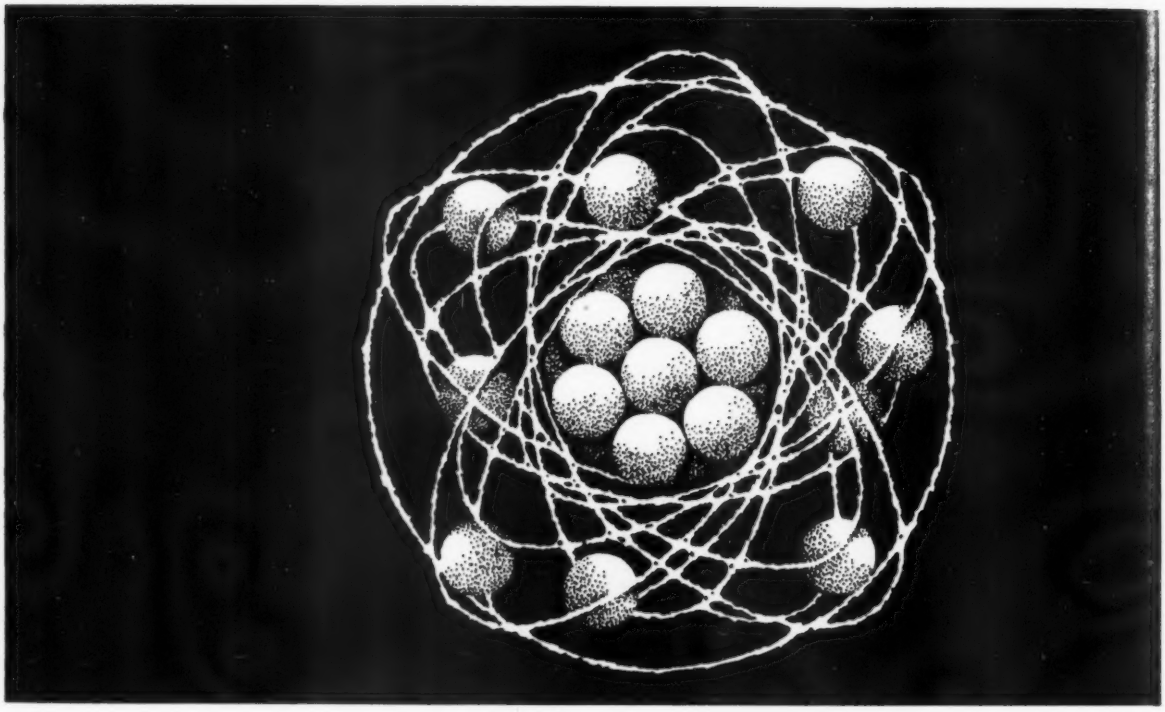

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External means are used in order to urge the disc sealing ring on to or away from the valve seat for closing or opening the valve. Operation can be effected according to requirements by hand, electric, pneumatic and hydraulic means.

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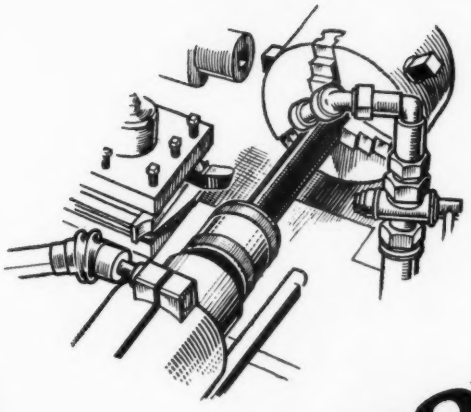

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The remote handling and machining of radio-active materials calls for design and construction of equipment by engineers who have a sound background in special-purpose machinery and machine tool production. More important, they must have a detailed knowledge and appreciation of the problems peculiar to the Nuclear Industry.

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We have both the engineering skill and "know-how." With the close collaboration of the United Kingdom Atomic Energy Authority, we have already designed and installed equipment at the Dounreay, Windscale and Springfields plants.

The illustrations show the exterior and interior installation of a remotely controlled precision lathe for the machining of irradiated fuel elements at Dounreay.

We shall be pleased to visit you at any time and you are cordially invited to our works where selected films and a most interesting range of activities can be seen.

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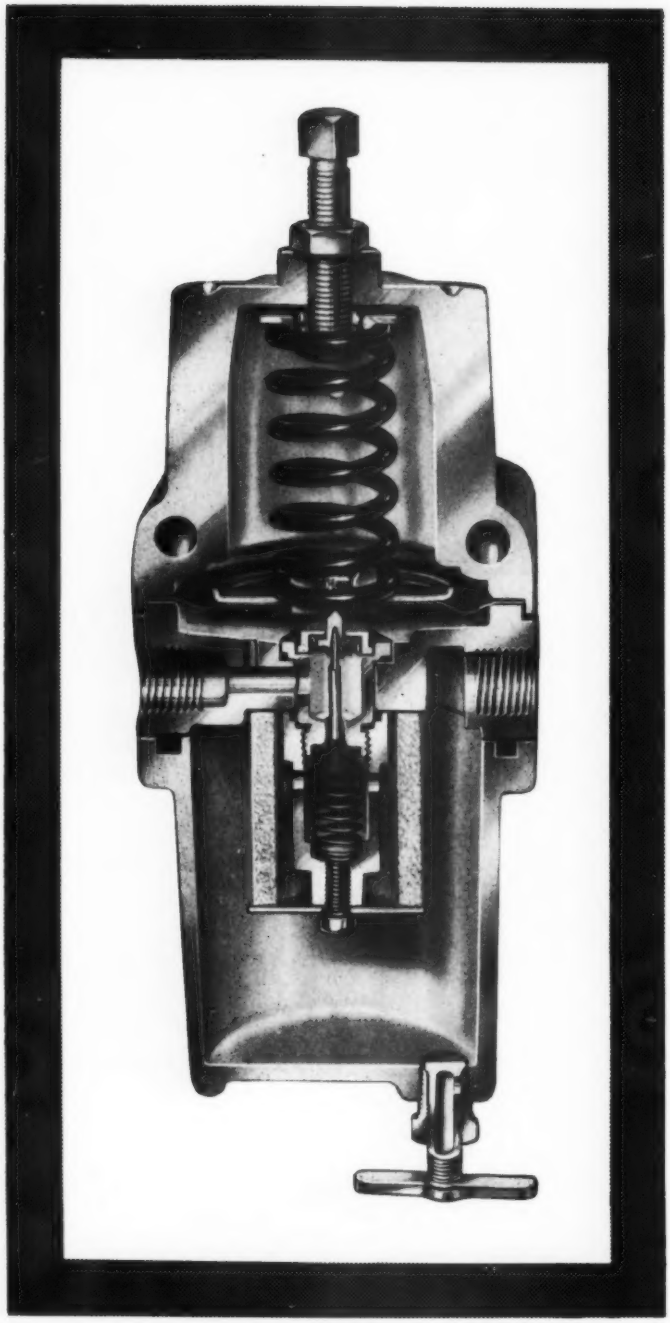

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* Exceptionally flat pressure flow characteristics
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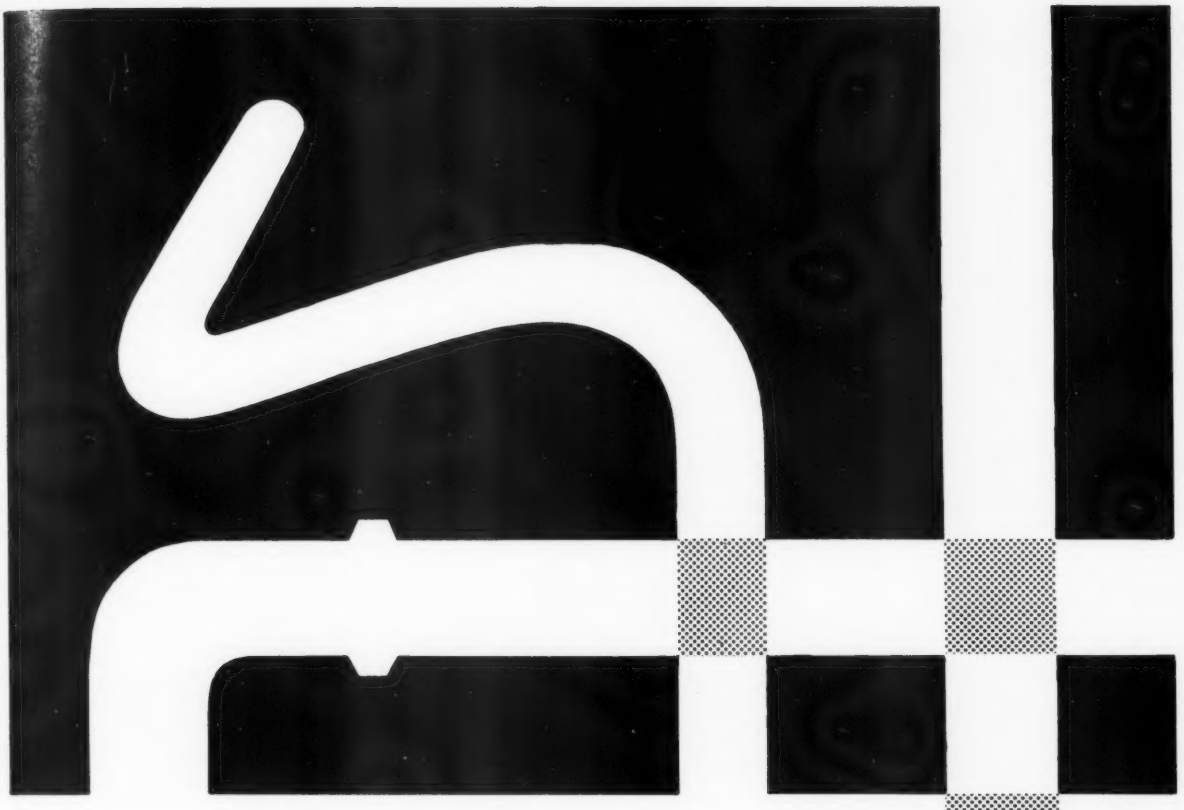

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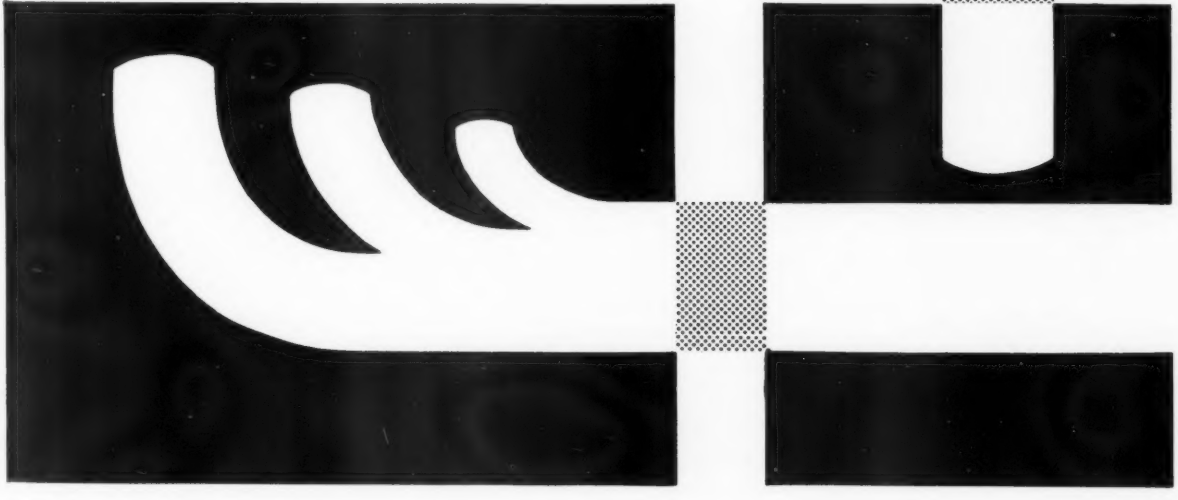
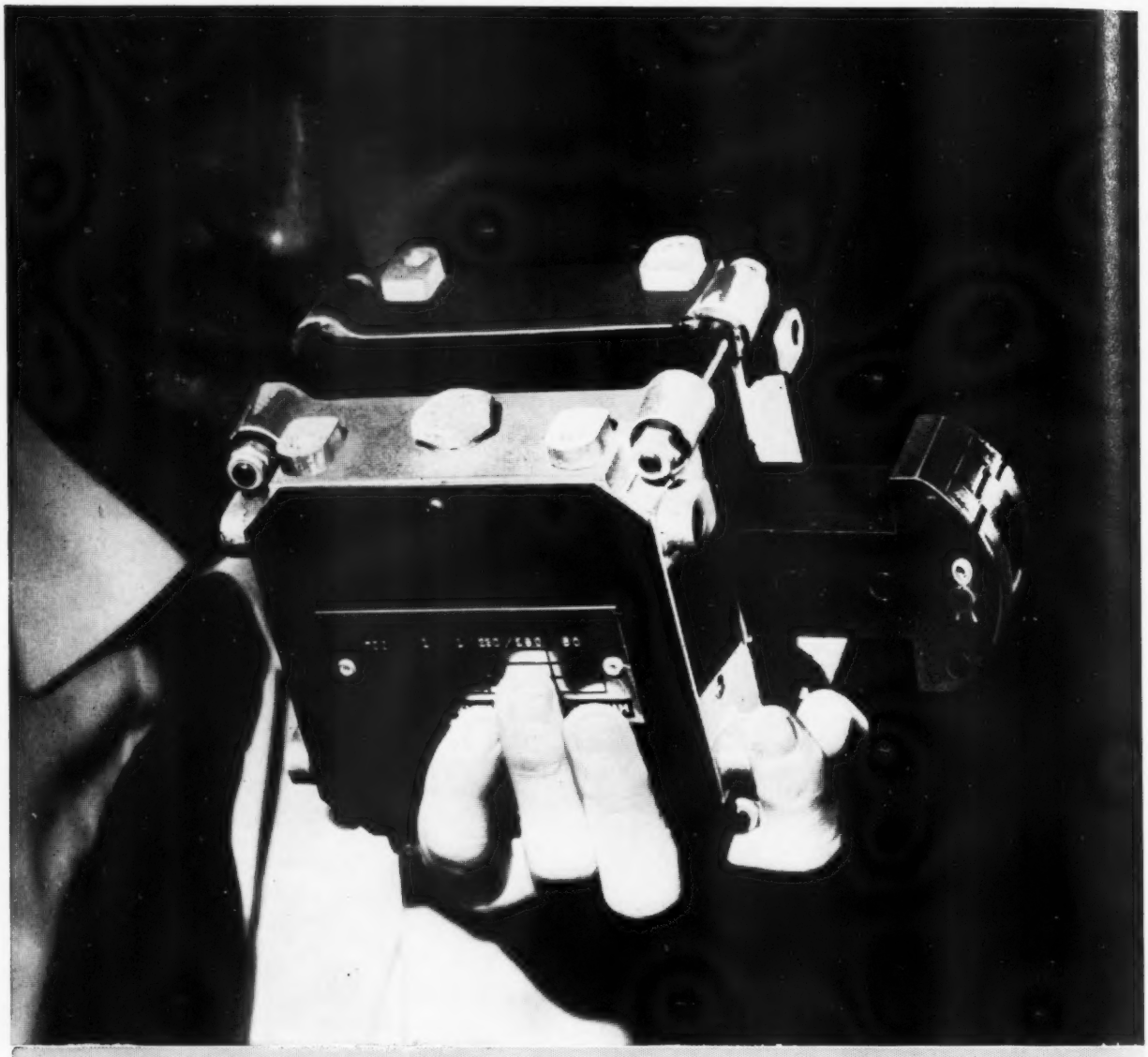
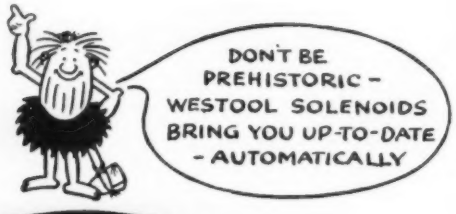




WESTOOL SOLENOIDS



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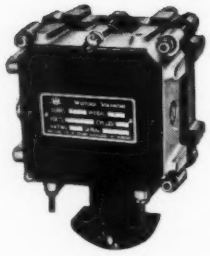
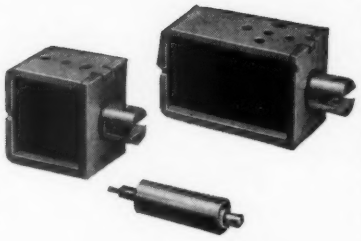


Series 700 A.C.



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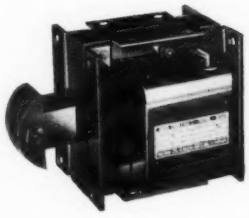
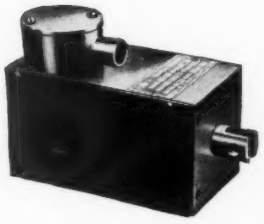
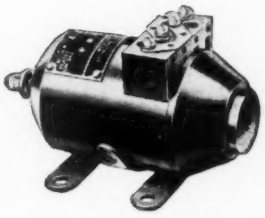


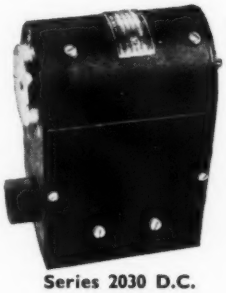
Series 600 A.C.



Series 'DK', D.C.



Series 1174 D.C.



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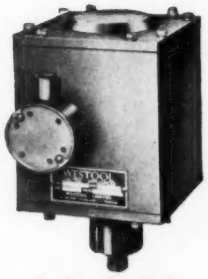

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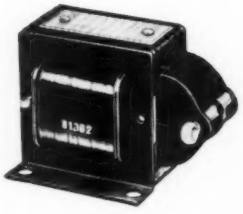

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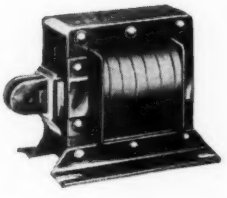
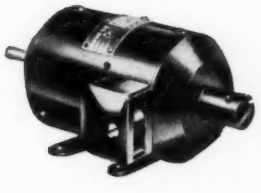


Series 400 A.C.



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OUR VALVES HAVE MANY FACES

Did you know that each one of our automatic control valves has a personality of its own? Take 'Safety Cut-out', for instance. Now, he's a careful type who shuts up like a clam whenever his electrical circuit is disturbed and flatly refuses to allow either liquids or gases to pass. Or there's 'Balanced 3-way'. This fellow is a leader and controls other chaps doing all the hard work — Pneumatic and Hydraulic cylinders for example. We have over 100 different 'types' of valves for every kind of automatic or remote control system involving water, steam, coal gas, oil, air and many other industrial liquids and gases. They don't use glands, stuffing-boxes or driving shafts and, what's more, they have a reputation for hard work, long life and the utmost reliability. Full technical details of this family of automatic control valves are contained in our new brochure No. 64. Why not write *NOW* for your copy?

Well over 100 of them, in fact. A 'type' to suit every requirement.

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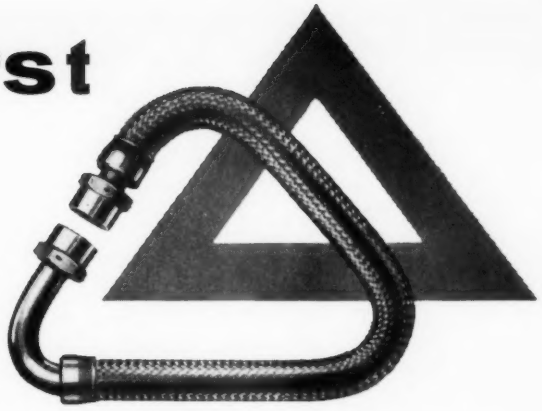
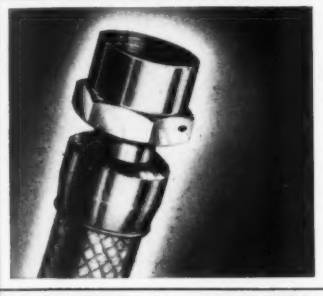


AVICA-FLEX

BELLOWS

(*including precision barometric units*, with closely controlled spring rate tolerances). For use in gas and fluid ducting systems for control of expansion or contraction, and to allow for misalignment. Other uses include shaft seals and glands. Available in stainless steel and other metals.



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STAINLESS STEEL FLEXIBLE PIPE ASSEMBLIES

For conveying gases and corrosive fluids at temperatures from −196°C to as high as 450°C. Available from ⅜" up to 4" diameter.

specify **AVICA** flexible assemblies and components

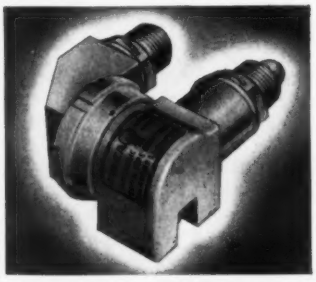
Where pressures or temperatures reach unusual extremes and vibration may be severe, take no chances—insist on AVICA pipe assemblies and components. Tested and proved by 20 years of service and used by the U.K.A.E.A. and throughout the nuclear engineering field, AVICA products are renowned for absolute dependability. Any problem of piping design or installation can safely be entrusted to Avica engineers.

RIGID TUBE COUPLINGS

With mechanically attached V Flange or bolted flange connections. No welding. No brazing. Leak-proof. Pressure tight. Will withstand extremes of temperature and vibration.

SYNTHETIC RUBBER FLEXIBLE PIPE ASSEMBLIES

Used to carry petrol, oil, air, steam, hydraulic fluids, for machine tools, hydraulic presses, mining equipment, at pressures up to 3,000 p.s.i. Size range ⅜"—2". Temperature range −40°C to 160°C.



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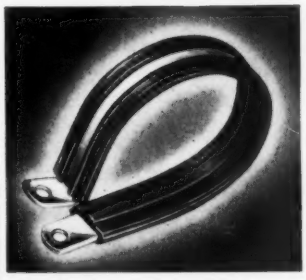
To provide rotary or angular movement in rigid or flexible pipe systems. In pipe sizes up to 1" for pressures up to 4,000 p.s.i.



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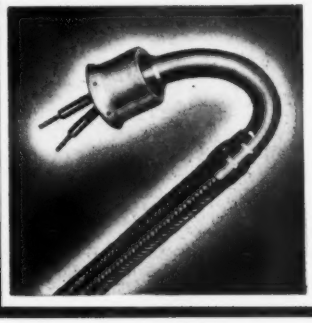
To hold piping and electrical cables. The rubber cushion absorbs vibration, can be renewed when worn or perished.



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Electrical wiring protected by rigid or flexible conduit from heat, oil, moisture and vibration.

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AVICA EQUIPMENT LIMITED

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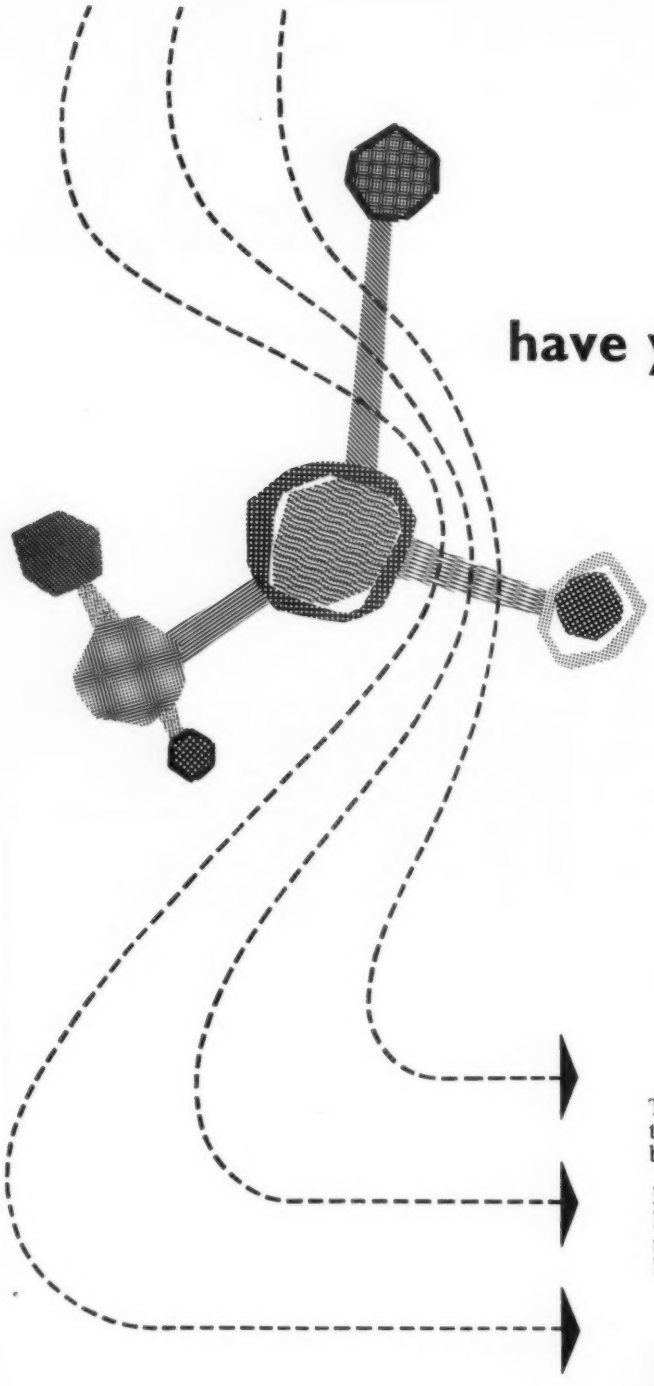

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If your needs are drop forgings* in special alloy, heat and creep-resisting steels or in special non-ferrous alloys, you'll solve many problems by consulting . .

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low pressure butterfly valves

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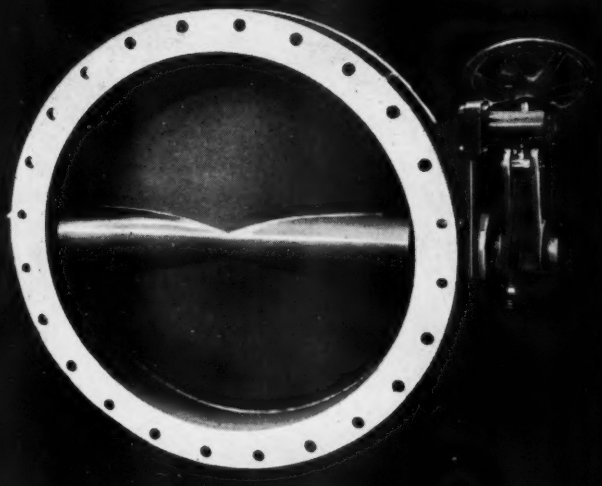
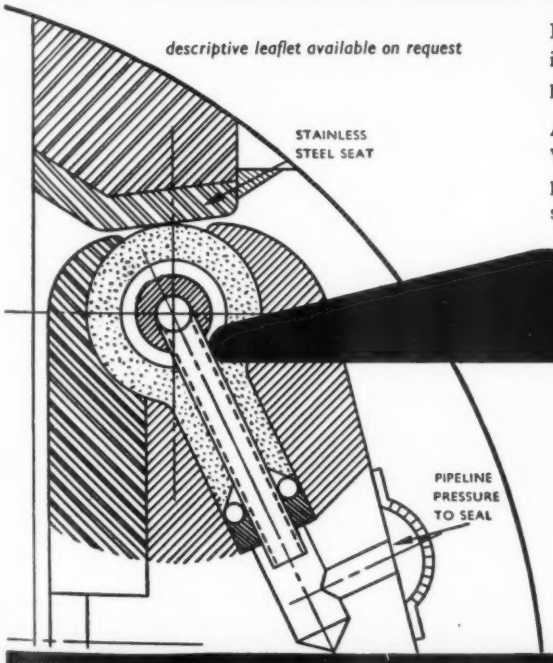
The reliability of this patented method of sealing has been proved in hydro-electric installations—after 25 years of service at heads up to 500 ft *the original seals were still intact.*



descriptive leaflet available on request



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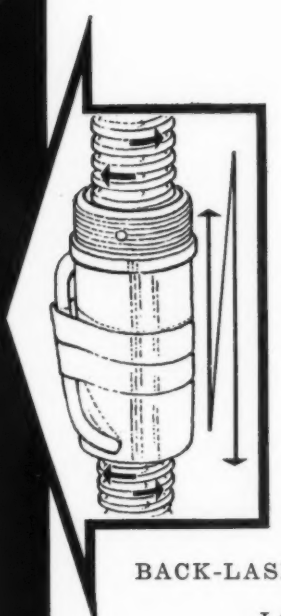

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BACK-LASH ELIMINATION

LONG LIFE

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Up to 80% reduction in power can be achieved for actuation compared with conventional methods.
Ability to run at high temperatures with and without lubrication.
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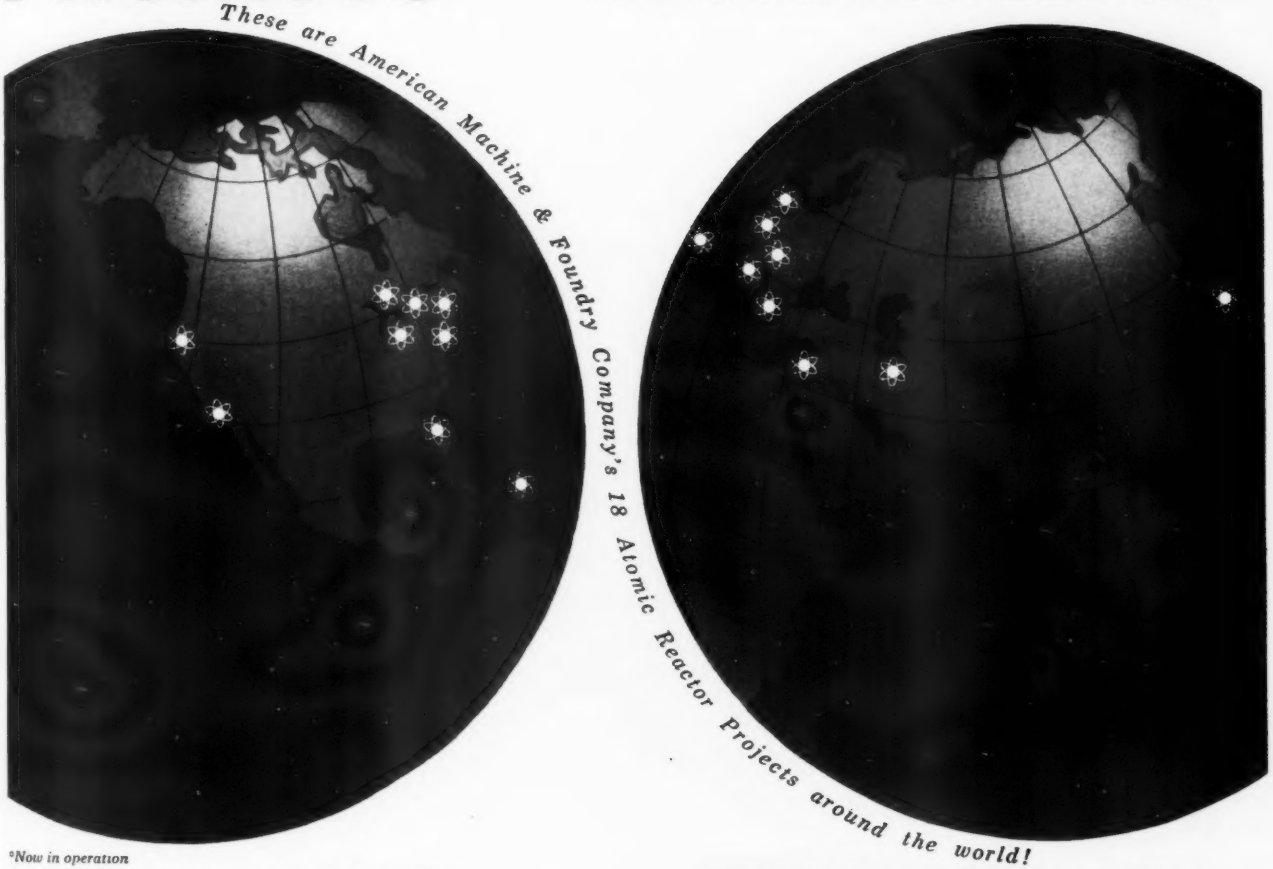

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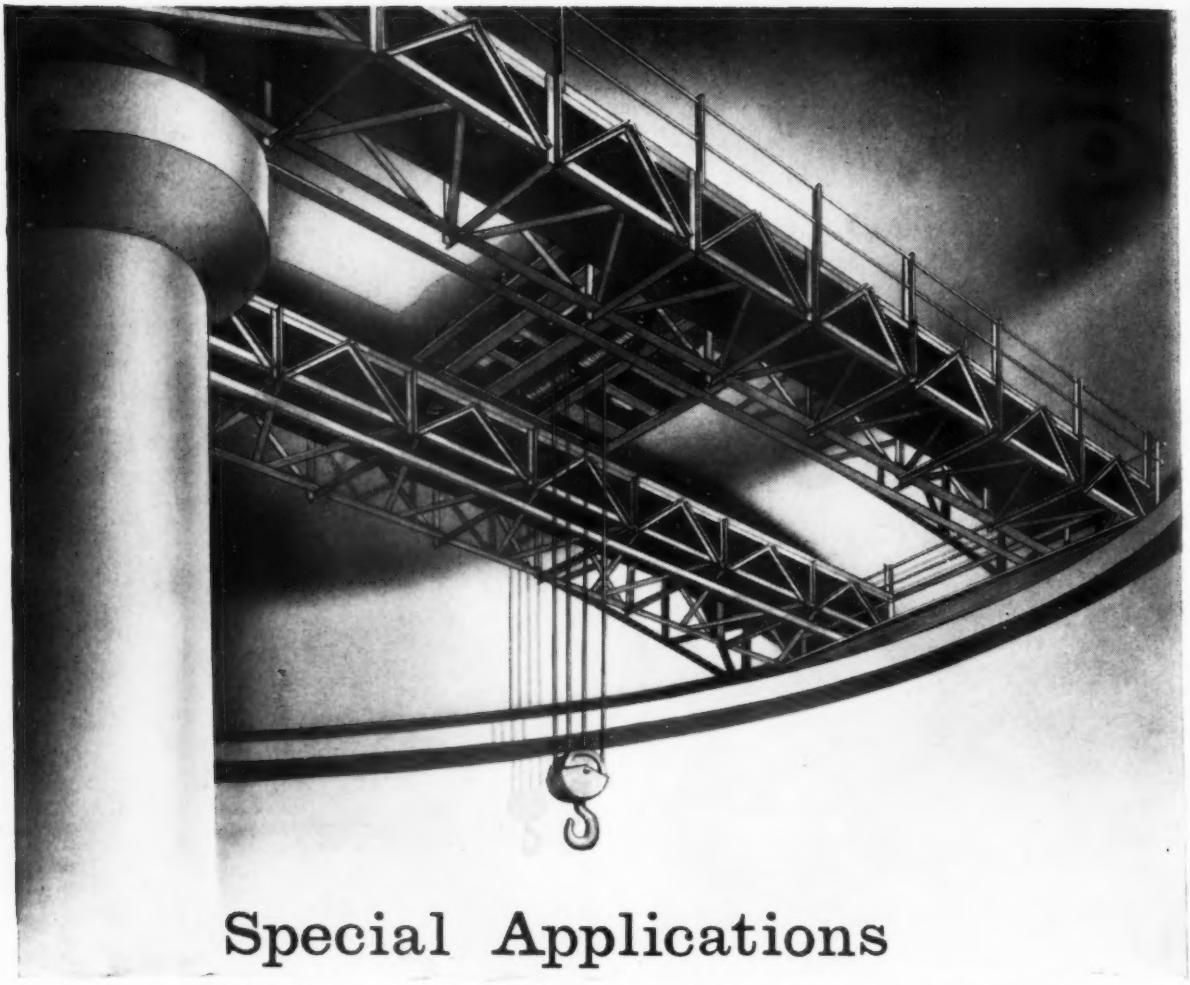

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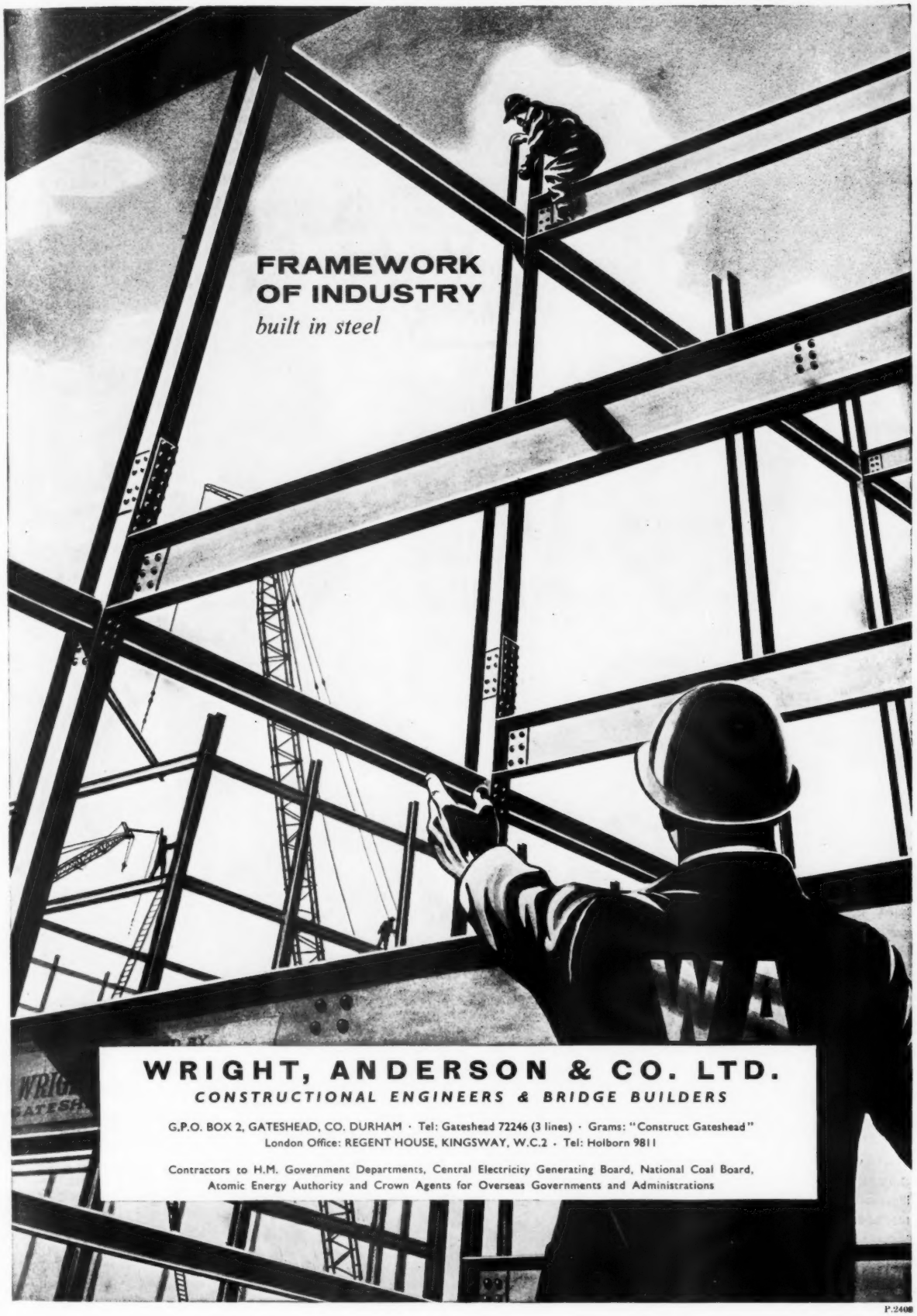
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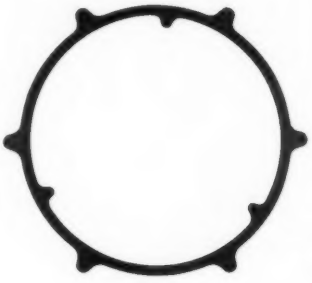
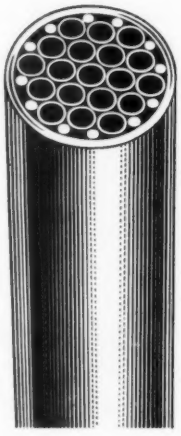
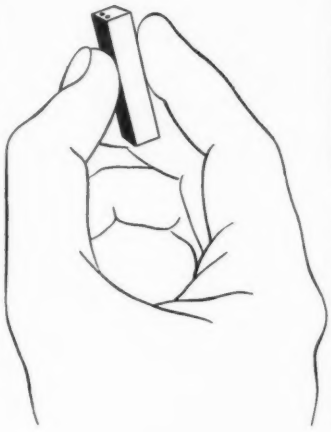
A stainless steel tube with external and internal ribs. The tube body is 1.650″ o/d x .060″ thick; the ribs are .093″ high x .125″ wide.





Multibore tube with 19 holes. The outside diameter of the large tube is .447″ and the smaller tubes are .053″ o/d.

A square section tube in mild steel .25″ A/F with two asymmetrical bores each .0625″ diameter.



Designers have a habit of asking for the impossible, but in a surprising number of cases Accles & Pollock produce an answer that enables the production people to translate the concept on the drawing-board into a physical, functional form. Accles & Pollock welcome all such opportunities to co-operate in developing new applications in the form of tubes and tubular sections.

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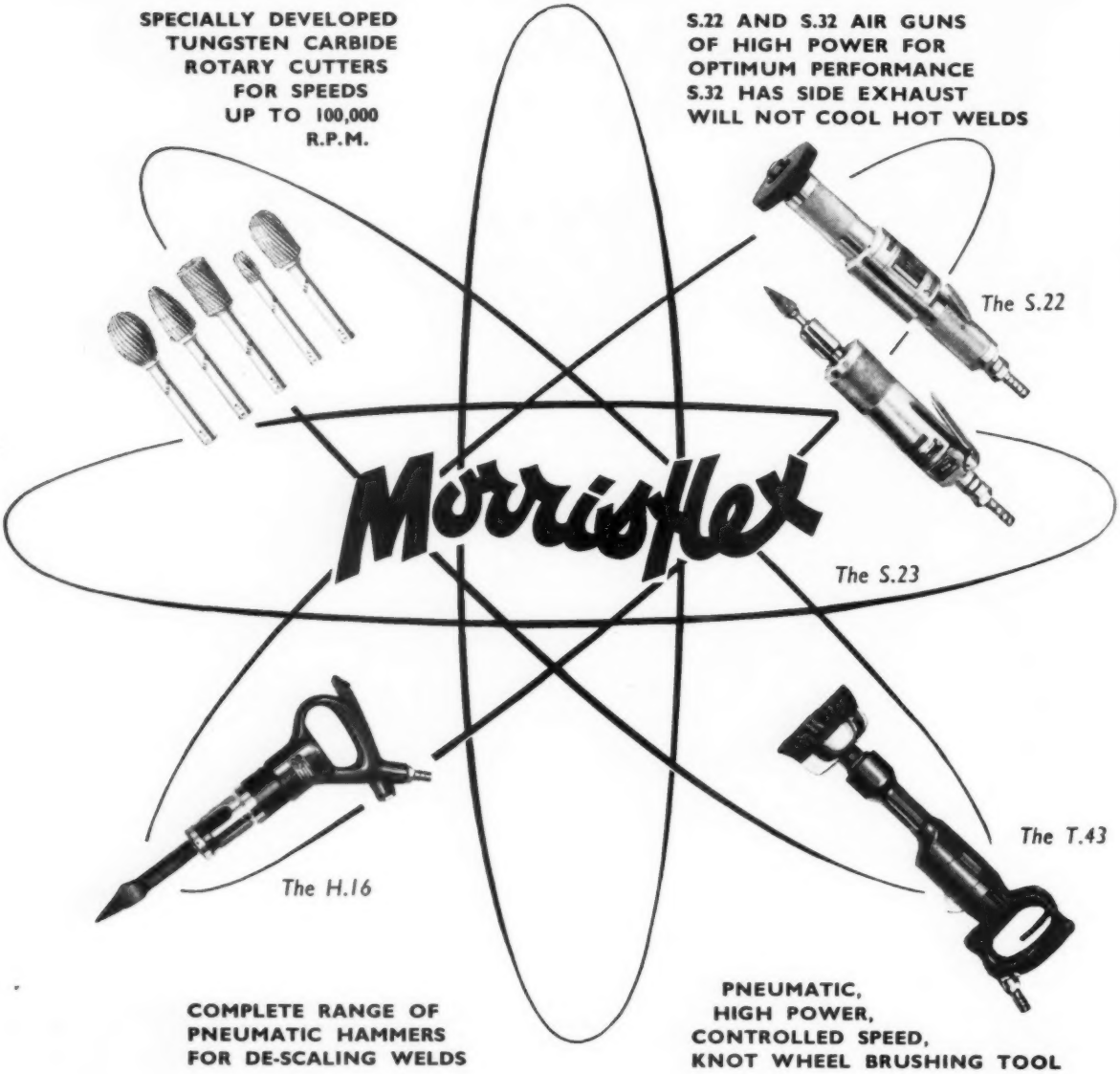

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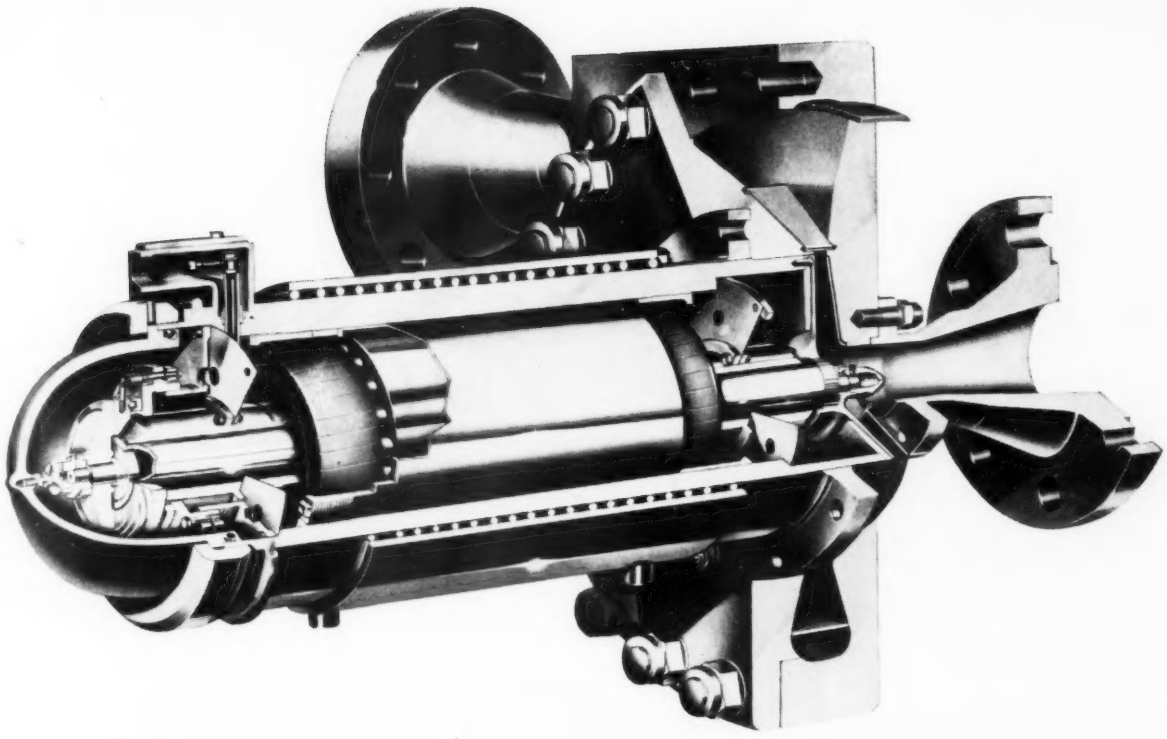

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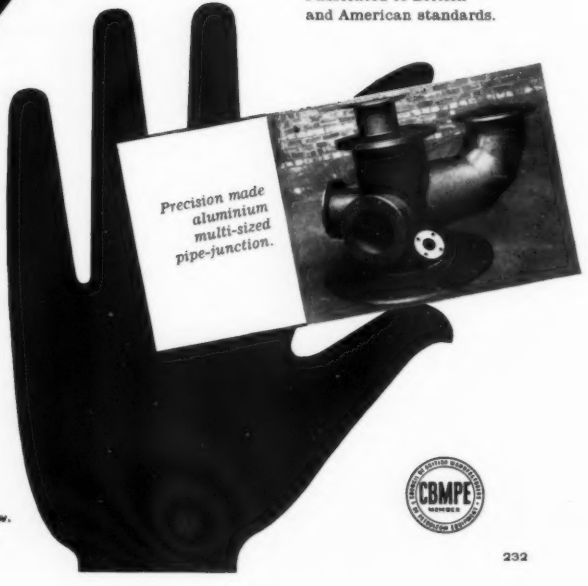

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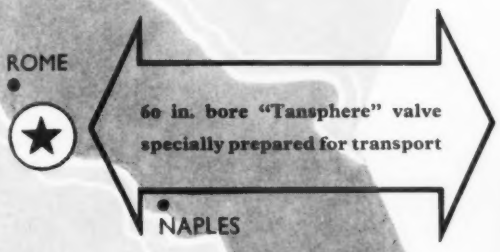
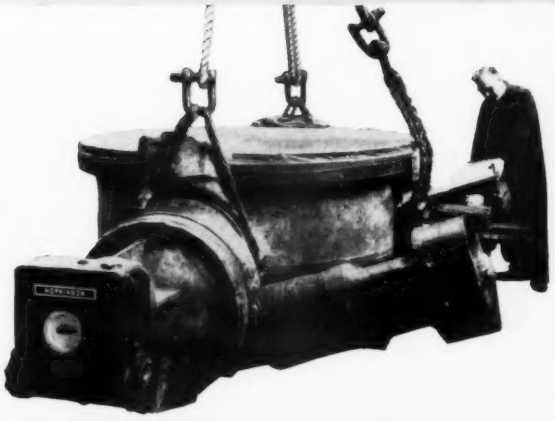
HOPKINSONS' VALVES





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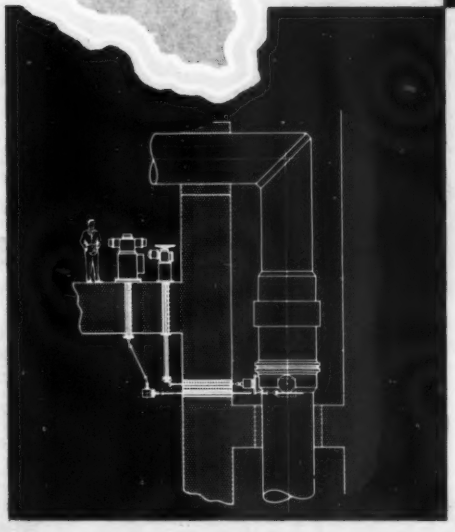
LATINA



Hopkinsons' "Tansphere" butterfly valves for gas-tight isolation duties between the reactor and steam generating plant are on order for the Latina Nuclear Power Station, Italy.

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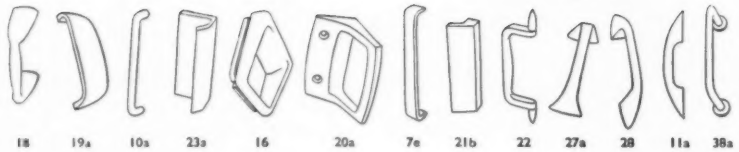

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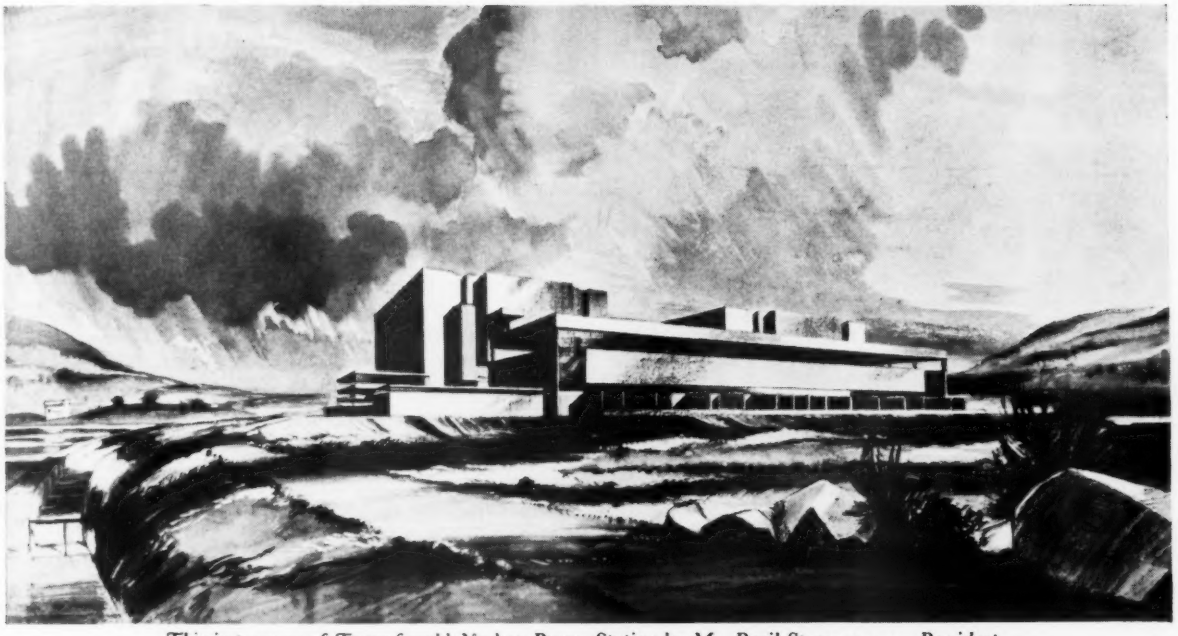
Trawsfynydd

NUCLEAR POWER STATION



This impression of Trawsfynydd Nuclear Power Station by Mr. Basil Spence A.R.A., *President* R.I.B.A., *Consultant Architect to Nuclear Civil Constructors, shows how the design blends into the landscape of Snowdonia.*

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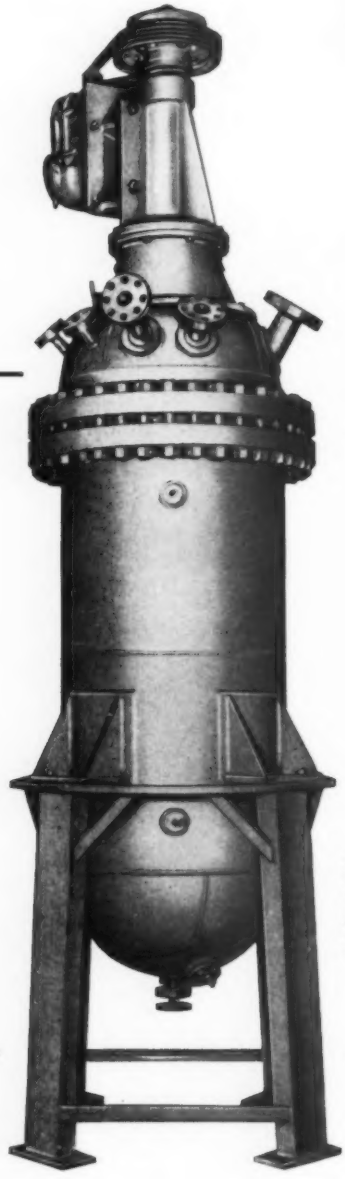

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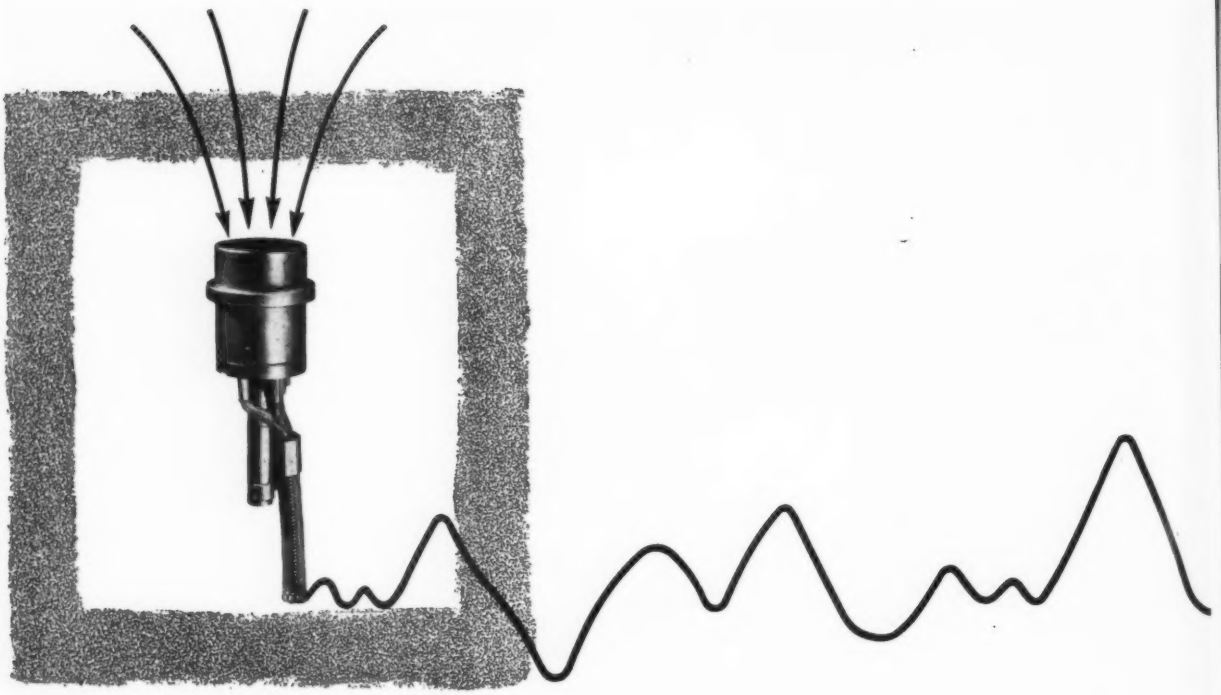

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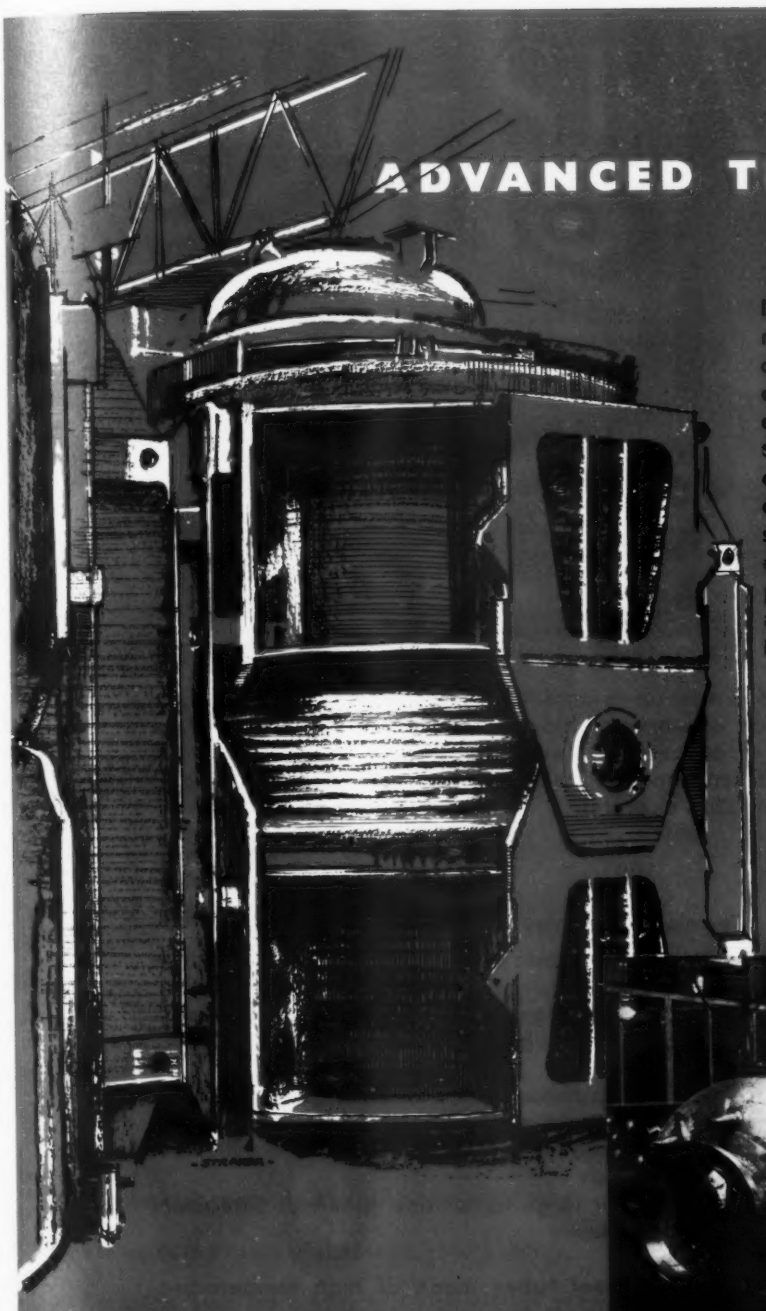

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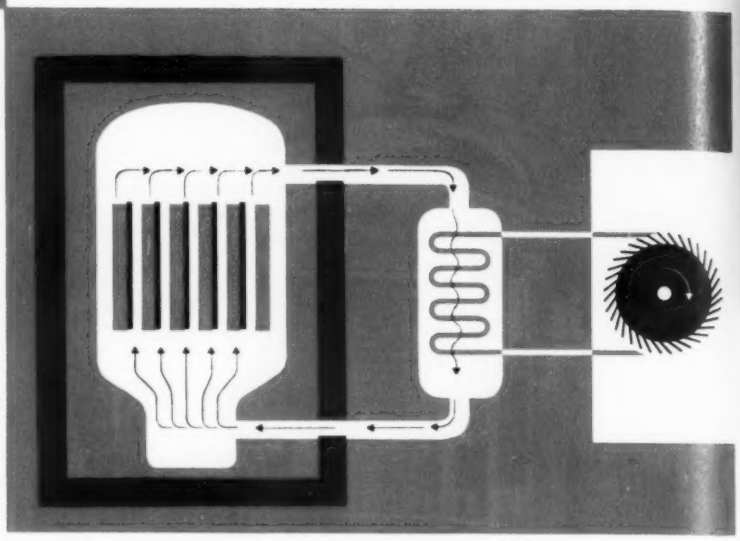

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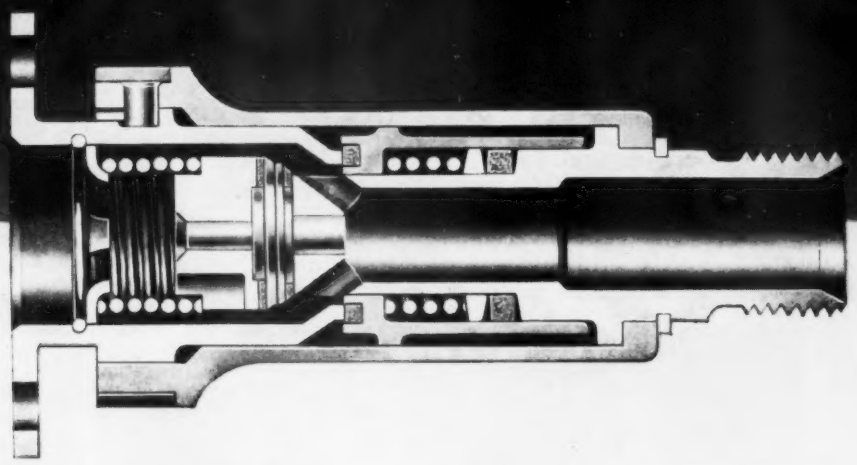

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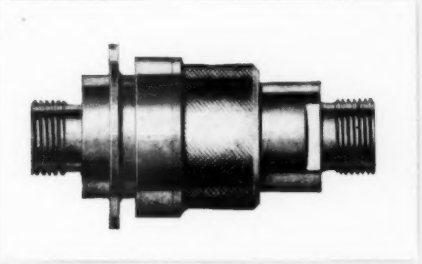

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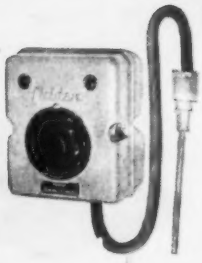

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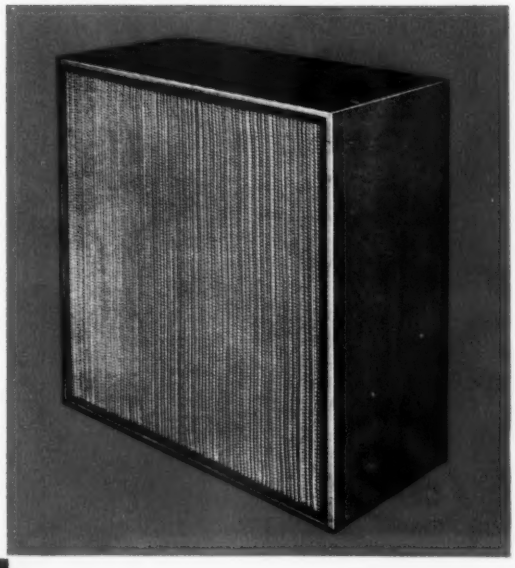

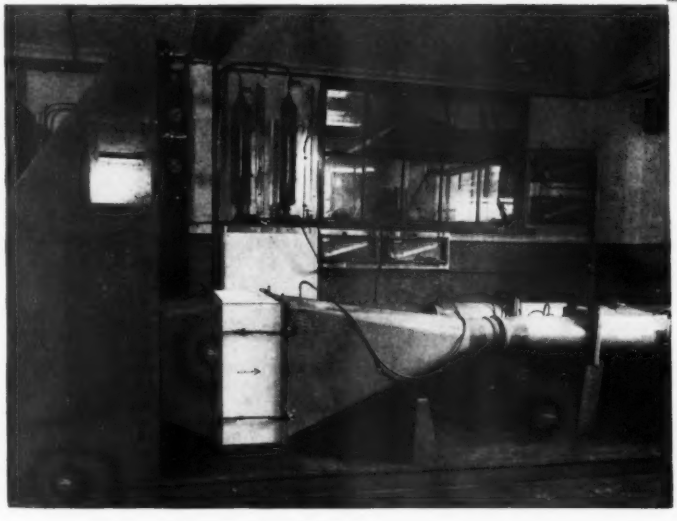

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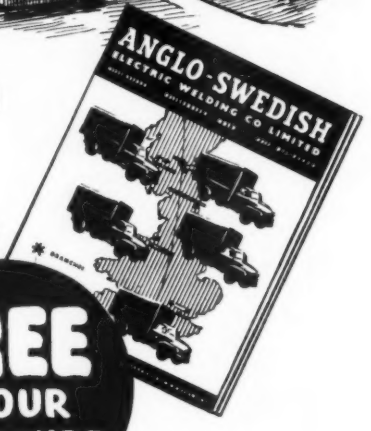

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Microscopic scattering cross section (barns)	5.09	5.09
Macroscopic absorption cross section ($cm^{-1} \times 10^{-5}$)	38.30	33.67
Macroscopic scattering cross section (cm^{-1})	0.432	0.432
Average logarithmic energy decrement per collision	0.158	0.158
SLOWING DOWN POWER	0.0684	0.0684
MODERATING RATIO	177.5	203
REFLECTING RATIO	1125	1285
DIFFUSION LENGTH	49	52

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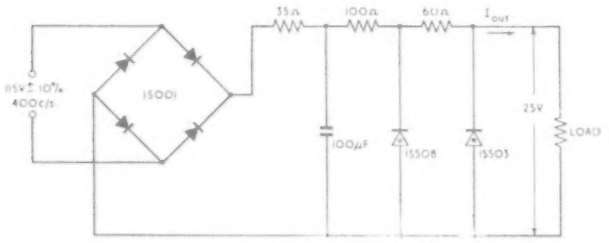
type	zener voltage Vz @ Iz volts	zener current Iz mA	zener impedance Zz (max) @ Iz ohms	reverse current LIb @ −10V 25° C µA	power dissipation P(max) Ts = 50° C watts	typical temp. coefficient %/° C
1S501	22	150	4	10	8	0.08
1S502	24	150	4	10	8	0.08
1S503	27	150	4	10	8	0.08
1S504	30	150	5	10	8	0.08
1S505	33	150	5	10	8	0.08
1S506	36	150	6	10	8	0.09
1S507	39	150	6	10	8	0.09
1S508	43	100	7	10	8	0.09
1S509	47	100	8	10	8	0.09
1S510	51	100	10	10	8	0.10
1S511	56	100	11	10	8	0.10
1S512	62	50	14	10	8	0.10
1S513	68	50	16	10	8	0.10
1S514	75	50	24	10	8	0.11
1S515	82	50	26	10	8	0.11
1S516	91	50	40	10	8	0.12

Actual Size



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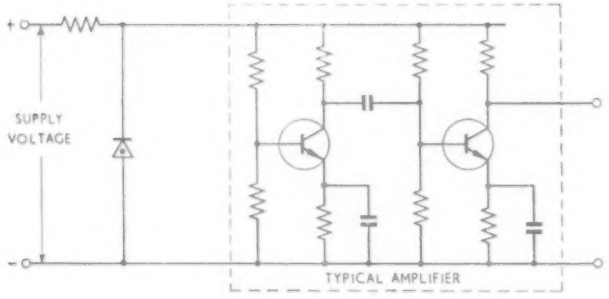

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Nuclear Power

PUBLISHERS COLUMN

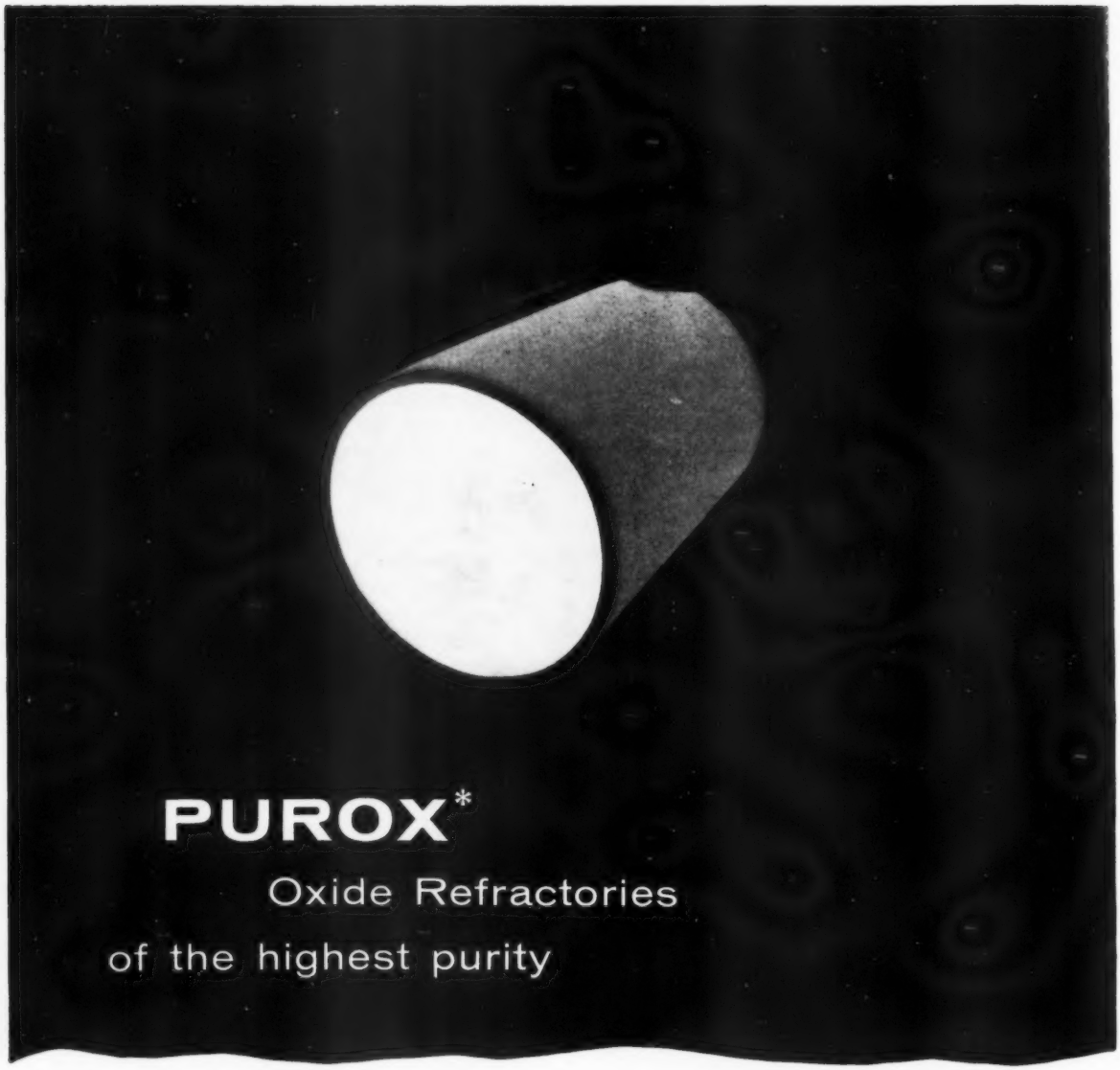
Back to normal

To most readers of magazines the printing dispute has now faded into the more or less distant past. It is beginning to fade for publishers too, but more slowly, as the printing industry gets into its stride again. Though NUCLEAR POWER was one of the few magazines to continue right through that troubled period, the publisher has been too occupied in making sure that 'we always appear' could continue to be the maxim of the firm to find time for a publishers column. But things are getting back to normal, and one of the most refreshing sights to be seen around the building for some months was a heated argument between the editors of CONTROL and NUCLEAR POWER on whether commas or spaces should separate groups of three digits in large numbers!

Most publishers and printers have a uniform way of printing abbreviations and mathematical symbols and of spelling certain words that have recognized alternatives. This is known as 'House Style' or 'Style of House.' With NUCLEAR POWER we have had such a house style which has been retained with few changes since we started in 1956. When another Rowse Muir journal, CONTROL, was started last year, it, of course, had its own editor and was printed at a different firm. From the start, it began to develop along its own lines, with a house style becoming in several respects different from that of NUCLEAR POWER. A few months ago it was decided to bring CONTROL to the firm that prints NUCLEAR POWER. It then became apparent that the house-styles should be unified to avoid confusion amongst the compositors and the two editors have finally found time to get together and hammer out a joint style. This was quite a battle with both sides having to make concessions. However, we have now got it and we hope to have it a long time.

For mathematical abbreviations we decided to stick closely to the British Standards Institution's BS: 1991 with two minor exceptions. We were not particularly happy with it but it has been out about five years now and printers are beginning to become familiar with it. It's not going to be easy to write mile/h for m.p.h. or rev/min for r.p.m. but we'll try.

In connexion with spelling we have always been guided by the Concise Oxford Dictionary, or the COD as it is affectionately known.



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SIR! LETTERS TO NUCLEAR POWER

The Editor welcomes correspondence for publication

First principles, not standards

SIR: I have read with interest the letter on page 69 of your August issue from Mr. M. T. C. Wallace. He raises an interesting and important point. I would like to comment briefly on one facet of nuclear engineering particularly appropriate to Mr. Wallace's reference to 'boiler engineering.' British Standards are intended to represent good current practice; in the field of boilers and pressure vessels the insurance organizations also publish rules which have the force of standards. These organizations must obviously ensure that the vessels they insure are safe and hence both their rules and British Standards are inherently conservative. If Mr. Wallace's plea for nuclear standards is intended to limit the freedom of the designer to the same extent as it is limited by, for example, BS 1500, it is to be resisted. Construction of the containment vessels for our nuclear power stations has been a project so different from conventional pressure vessel and boiler design that the ordinary rules have been inapplicable. Thus the designers have had to work from first principles and by throwing off the yoke of established practice have been able to produce economic designs based on modern knowledge of the behaviour of metals under different forms of load. To those of us employed on research in the design of pressure vessels the nuclear power vessels have indeed been a godsend. They represent one of the few occasions on which a design can be based on logical grounds and can therefore take advantage of recent research work. We are now approaching the stage where the satisfactory incorporation of the results of research to the nuclear vessels is paving the way for the application of these results to more conventional designs.

Abington Hall, Cambridge P. H. R. LANE
Head Member Service Dept., British Welding Research Assn.

Dismay and disillusion

SIR: The Government's action in appointing Sir Roger Makins as chairman of the UKAEA has caused widespread dismay and disillusionment amongst the rank and file in Authority establishments where for inspiring leadership there is no substitute for a scientific reputation. His predecessor, Lord Plowden, admittedly is no scientist but at least he had accumulated many years' experience of technical and industrial matters. The recent appointment of a Civil Servant as a member for Industry was bad enough; this latest move is the end. What a pity Sir Alexander Fleck could not have been persuaded to take on the chairmanship: his unique qualifications and experience could have really transformed the whole atomic energy picture. But have we not reached the point where the AEA as such has outlived its usefulness? Why not transfer all weapon activities back to the Ministry of Supply and give the civil side to the Ministry of Power who in turn would contract out nearly all development and research work. Fundamental work should be done by the National Institute which would, of course, be expanded accordingly. Would you please allow me to sign myself

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Nuclear Power
REACTORS MATERIALS INSTRUMENTATION PROCESSES IRRADIATION
SEPTEMBER 1959 VOLUME 4 NUMBER 41

An affable watchdog

AS MUCH TO ITS OWN SURPRISE as anyone's, the Atomic Energy Authority has come remarkably well out of the most searching enquiry ever held into its organization and activities. The select Committee on Estimates, a body better known for digging out disgraceful secrets than bestowing compliments, has many kind things to say in its 40,000-word report on the Industrial Group (now split into the Production Group and Development and Engineering Group). Its basic organization is declared to be sound and the new divisions approved; its reversal of some parts of the Fleck Committee policy is supported; its system of financial control, by and large, is blessed. All this reflects great credit on the men who had to create the Group so hastily. But though a friendly attitude is maintained right through the report, the Committee was obviously troubled by two major anomalies in the present set-up.

The integrated programme

The first concerns the fast reactor. Authority feeling has been lukewarm about it for some time. Yet the only factor which could make a significant difference in the cost of power from the first CEGB stations is the level of the credit allowed from the plutonium produced and this depends on a civil use being found for it. The Committee has now re-endorsed the view that fast reactors offer the only way out and strongly recommends that the whole programme should be accelerated to solve major problems by 1966 at the latest. With this proviso it backs the construction of admittedly uneconomic stations now so that they may provide the plutonium for the elysium to come.

The other main anomaly observed by the Committee concerns the relationship of the AEA with industry. While the Authority has failed to recruit enough men to carry out all its plans—the decision to limit recruitment in future to 8% a year is no more than a recognition of the amount of new staff it is likely to get—private industry has facilities and staff under-employed. In fact necessary work which industry could have tackled has been postponed by the Authority.

The AEA evidently saw a major criticism coming here and kept one jump ahead by making its own reappraisal. It has decided to treble the amount of piecemeal design and development work put out to industry while maintaining its insistence that industry is not yet capable of handling a development contract for a complete reactor system. The Committee, faced with this compromise, has agreed to it, but the Authority has not escaped scot-free. Its habit of huddling over a system in comparative secrecy until the prototype stage, and in particular its keep-off attitude on Dounreay, is adversely commented on, and the report explicitly urges the Authority to bring industry into the picture at a much earlier stage, by fuller technical discussions and by inviting them to attach staff to reactor experiments—to really keep them in touch with forward thinking, instead of retiring behind a screen of papers and reports.

The Committee, not surprisingly, came to the conclusion that the AEA's industrial groups are in danger of getting bogged down in marginal improvements on the Magnox reactors and the high proportion of staff still working on these came under fire. Though the Committee evidently underrates the magnitude of the problems remaining to be solved, it is undoubtedly true that many of these could be undertaken by industry or the CEGB, and the report states that this should be done.

Too early or too late ?

On the question of giving industry development contracts for complete reactor systems the report is less positive. The Authority will certainly claim that the Committee has supported its own view, but this section of the report needs careful study. The findings seem to amount to an unenthusiastic negative, with a recommendation that the possibility should be borne in mind, especially regarding smaller reactors for export and marine purposes—which the Authority still have no intention of developing specifically. Indeed, the Authority has managed to infect the Committee with its own pessimism about the problems of fuelling and selling a small reactor if one were developed, and is obviously responsible for the report's major inconsistency. It is too early to develop a small reactor, the argument runs, because it will need enriched fuel and this won't be cheaply available from the thermal stations until the middle 1960's. Elsewhere the report says that in any case 'the Americans have much more experience of the designs that would probably prove best.' In other words it is already too late! This sentiment, which must certainly not go unchallenged, is typical of a vein of timidity which comes to the surface here and there in the report. The Authority is urged (as if it needed encouragement) to limit severely the number of reactor systems developed; its attitude to the steam-cooled heavy water-moderated reactor as merely an insurance against failure of the advanced gas cooled-type is endorsed, the high temperature reactor gets only a brief and cool mention as a faint possibility, and industry and the AEA are told that if another system is developed it should be as near in type to those already known as possible.

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Worldview

the month in atomic energy

AEI-NPPC tie-up

The recent collaboration agreement between the Nuclear Power Plant Company (NPPC), and AEI-John Thompson Nuclear Energy Company had its origins in the days when Sir Claude Gibb headed the NPPC. The companies have indicated to the CEGB that they wish to submit tenders for the 500 MW Dungeness and the 600 MW Sizewell stations. This scheme of cooperation is expected to result in the formation of a new joint company before the date that the next tender, for Dungeness, has to be submitted and by such action anything up to £200,000 can be saved in tendering costs.

Cooperation will not be limited to large power station projects, but is to extend to every aspect of nuclear engineering, including ship propulsion, research reactors and controlled thermonuclear reactions. While a certain amount of overlapping in activities between individual member companies of the group is unavoidable, it will at least ensure that the most efficient and competitive facility will be employed. Moreover, it will enable the potential client to choose from alternative companies such major items as turbines, generators, graphite machining facilities, structural and civil engineering services.

The group is already in a position to offer two designs of power generating stations and three research reactors—the 5 MW Merlin and the 10 MW Dido or Pluto types. Combined research facilities will be the most extensive of the UK nuclear engineers and include the Merlin reactor, the only industrially owned CTR facilities, Sceptre III and IV—the latter just being commissioned—and the Parsons nuclear fuel research establishment. Already NPPC have an agreement, worth some £200,000 per annum, with AGIP Nucleare covering the training of Italian personnel and collaboration for the construction of possible further stations in Italy. While possibly, over a period of time, there will be some regrouping in the organization, and research activities better coordinated, it is not expected that any drastic personnel changes will occur.

On the marine side, the proposed collaboration will again have its beneficial effects, as the AEI group has an agreement with the US General Electric covering the design of small marine reactors and both the UK groups have designs in hand for a 22,000 shaft horsepower nuclear-powered mercantile vessel. Through NPPC's collaborative arrangements with Swan Hunter and Wigham Richardson full shipbuilding facilities would be available to the new joint group.

NIRN²s first at power

The 50 MeV proton linear accelerator at the Rutherford High Energy Laboratory accelerated protons up to its full energy level for the first time on July 12. Designed and constructed by Metropolitan Vickers in collaboration with AERE who also carried out the basic development work, the accelerator is the first to come into operation at the National Institute for Research in Nuclear Science Rutherford Laboratory. It will be used by a resident team at the laboratory, the AEA and physicists from universities.

Safeguards now in force

Paris—The OEEC Convention on the Establishment of a Security Control in the Field of Nuclear Energy, signed by all OEEC member countries on December 20, 1957, has now been ratified by ten countries, so bringing it into force. The ratifying countries, in order of taking action, are the UK, Eire, Switzerland, Norway, France, Denmark, the Netherlands, Turkey, Germany and Belgium. The convention is particularly designed to ensure that joint nuclear facilities developed with the help of OEEC are used exclusively for peaceful purposes—it provides for certain sanctions to be applied for failure to comply with its requirements.

Parallel with the security control convention, a draft Convention on Third Party Liability in the Field of Nuclear Energy has been agreed upon by the Steering Committee of the OEEC European Nuclear Energy Agency. This includes liability for accidents arising in the course of transport of nuclear fuels and for which the same maximum liability, $M15, and time, ten years, as for accidents on site will be applicable.

Vienna—A panel of experts has been convened by the IAEA to draw up regulations to cover the transportation of radioactive and fissile materials including irradiated fuel elements. These will include control of criticality and dispersion of the heat generated within the sources. The aim is to ensure that the essential requirements should be uniform, comply with international and national regulations and liabilities and provide minimum safety measures which, as far as possible, are uniform for air, water and land transportation.

CANADA'S FIRST. The 20 MW(E) heavy water moderated Nuclear Power Demonstration (NPD) Reactor which is being built near Rolphton, Ontario, and is scheduled for completion in 1961

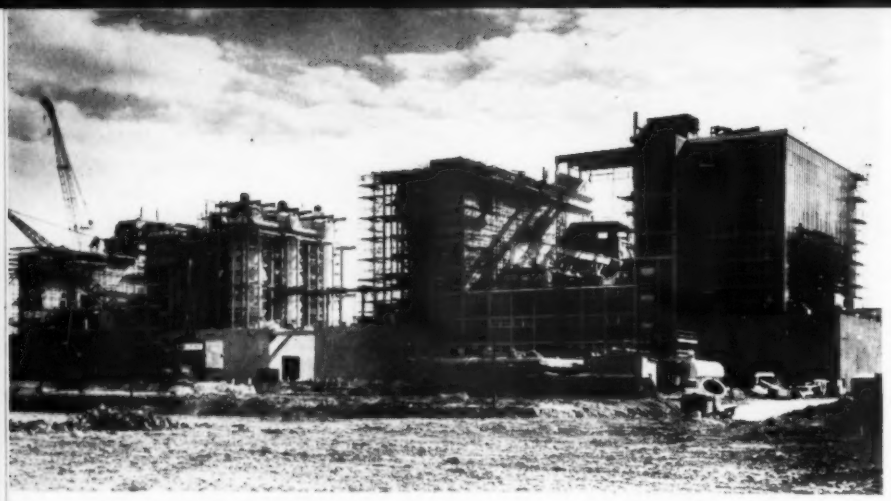
Credit for building

Brussels—Euratom and the Export-Import Bank of Washington have signed agreements covering the $M135 credit to assist in financing the construction of nuclear power plants under the Joint US-Euratom programme. The overall cost of this programme is expected to be at least $M350 and the balance will be raised from European sources. The loan of $M135 will be repayable over 20 years and interest will be charged at 4½% annually—this is a lower rate than that normally charged for development loans.

Rome—Some $M40 is to be lent by the World Bank to the Italian Fund for the South, to finance the Project ENSI at Punta Fiume, where the US General Electric are building a 150 MWe BWR.

To help industry

Brussels—The majority of the US/Euratom Joint Reactor Board members have now been nominated. For Euratom, the chairman will be Eildert G. Stijkel; financial member Pierre Nacivet; legal member Felix Oboussier; technical member Claude Ramadier—two other Euratom representatives will be named at a later date. For the United States AEC,



BRADWELL PROGRESSES. The final shape of this 300 MW(E) nuclear power station is now becoming evident. During the first week of this month, the eleventh boiler was lifted into position

the vice-chairman will be Amasa S. Bishop; legal member Marcus A. Rowden; financial member John C. Ryan; technical members Jarvis L. Schwennesen and Nelson F. Sievering—one other AEC representative will be named at a later date. In cases where a loan from the Export-Import Bank of Washington is concerned, a representative of the bank will also attend.

Initially, to implement the joint nuclear programme, the Board will evaluate the proposals received from European groups and companies for participation in the project; make recommendations regarding the acceptability of such proposals; and coordinate the execution of the overall programme

Fuel source in South America

Buenos Aires—Claims have been made that rich uranium deposits of high radioactivity have been discovered in the Province of Salta and technical experts from the Argentine Atomic Energy Commission are now carrying out extensive field investigations.

Tracers in sugar industry

Sydney—Following preliminary experiments at Lucas Heights, full-scale field testing in the use of radioactive isotopes to aid Queensland's sugar industry is to be carried out this year. The Australian AEC, in cooperation with the Bureau of Sugar Experiment Stations, will apply radioactive isotopes as tracers to test the efficiency of a sugar mill subsider which is used to remove solid impurities from the raw sugar solution.

UK seeks Australian aid

Sydney—The Minister for National Development is discussing proposals from overseas for the use of the Australian reactor, Hifar, to test nuclear power reactor materials. The General Electric Company-Simon Carves Nuclear Group are interested in having irradiation experiments carried out at Lucas Heights. The United Kingdom AEA are also investigating the practicability of using Hifar for the irradiation of beryllium metal samples; this work would be of particular value to the Australian AEC as they intend to investigate this material for use in their own power reactor programme (see *They said*, this month). With facilities fully booked in the UK for some time to come, using Hifar in this way will help to prevent development programmes getting behind

Canada looks overseas

Ottawa—During recent months the Canadian Minister for External Affairs has been finalizing agreements with overseas Governments and organizations which will give Atomic Energy of Canada Ltd. the opportunity to participate in future foreign projects. A bilateral agreement between Japan and Canada was signed in July, providing for cooperation in the development of atomic energy, especially in the field of electric power generation.

During August, Australia and Canada signed an agreement of cooperation through which Australia is to receive know-how, especially on the subject of natural uranium fuelled, heavy water moderated reactors.

Two agreements between Euratom Commission and Canada have been concluded—one provides for cooperation in the peaceful uses of atomic energy and will enable European industrialists to deal freely and directly with the Canadian atomic authorities. The other covers collaboration for a research programme centred on a heavy water reactor. To further these agreements, Atomic Energy of Canada Ltd. have invited some sixty reactor and fuel element manufacturers of the Euratom countries to visit Canada to study the construction of heavy water reactors.

Going it alone

Paris—The French atomic energy authorities are determined to press on with their plans independent of overseas assistance. Recently the G-3 reactor at Marcoule went critical and will be producing a net electrical output of 25 MW. Projects now on the drawing boards include naval nuclear power propulsion units and a uranium separation plant. The three nuclear power stations at present scheduled will be followed by a fourth in 1962. Between 1965 and 1967, some 1000 MW will be produced by nuclear plants. A new company to enter the French nuclear engineering field is the shipbuilding concern, Chantiers Navales de la Pallice, which is participating in the construction of the nuclear power station at Cadavache.

Iraq turns to Russia

Moscow—An agreement covering cooperation in the peaceful uses of atomic energy between the Republic of Iraq and the USSR was signed here on August 17. It provides for Soviet help in the building of a research reactor and isotope laboratory in Iraq, assistance in prospecting for radioactive ores and formulating research programmes, and the training of Iraqi personnel for developing the uses of atomic energy. This arrangement will, to a big extent, replace the facilities lost when the Baghdad Treaty organization moved its nuclear facilities and activities to Teheran.

Japan starts ship trials

Kobe—The Japanese shipbuilding concern, Mitsubishi, started trials at the end of July on a model of their mercantile nuclear powered submarine. This model, weighing nearly two tons, is some 28 ft long and has a diameter of 3 ft 3 in. It is undergoing stabilization trials, powered by an electric motor and at a depth of 20 ft travels at approximately 9 mile/h. If these trials, which continued through August, prove successful Mitsubishi will go ahead with the construction of their 35,500-ton commercial nuclear powered submarine design.

Nuclear research in the Pacific

Manila—The United States AEC is making a grant of up to $500,000 to the Philippine Government towards the cost of a reactor. This plant will form the nucleus of a research centre which is being set up at Diliman, Quezon City, eight miles north-east of here, for the University of the Philippines. General Electric has started building a 1 MW open pool research reactor and it is scheduled to come into operation at the centre by the autumn of 1960.

Swiss fall behind

Würenlingen.—The head of the Swiss Reactor Co., Dr. K. Sontheim, has warned his countrymen that they are falling behind in the field of nuclear engineering. Unless assistance is to be sought in the future from foreign industries,

new experimental facilities should be built now. The State should sponsor and encourage the establishment of at least two research centres and take steps to build up teams of experienced scientists to work on nuclear projects.

Progress on the Don

Moscow—The construction of the first reactor for the Novovoronezhskaya nuclear power station on the River Don is progressing well. The biological shielding, some 33 ft thick, together with the reactor foundations have been completed and the main combined reactor and turbine hall is now being built. The plant, when completed, will comprise two pressurized light water cooled and moderated reactors, using 1·5% enriched uranium, each having a gross thermal output of 760 MW, giving, through three 70 MW turbogenerators, a gross 210 MW electrical output (196 MWe net). The cooling water will be circulated at a pressure of 100 atmospheres at a rate of 120,000 gallons per minute, when its temperature will rise 25°C from 250°C on entry to 275°C on leaving the core. The reactor vessel will be 12½ ft in diameter and nearly 40 ft high (see *Worldview*, September 1957). The primary cooling circuit incorporates six tube and shell type heat exchangers and six circulating pumps as well as two nitrogen pressurizing tanks, per reactor. The first reactor is scheduled to go critical in 1960 and full power operation achieved by 1961 when the output will be linked with the unified power grid of the European part of the USSR. The station will also be used experimentally in connexion with the future Soviet nuclear power programme.

New facilities

Munich — The Siemens-Schückertwerke AG Argonaut-type SAR reactor at Garching, near here, has gone critical. This is the first German-built reactor to come into operation.

Karlsruhe—Another Argonaut-type reactor has been ordered by the Gesellschaft für Kernforschung mbH, for their K-II programme, from Siemens-Schückertwerke AG, who will be assisted in the construction by the companies Lurgi of Frankfurt and Pintsch Bamag AG of Butzbach.

Düsseldorf—A contract was awarded by the Arbeitsgemeinschaft Versuchs-Reaktor (AVR) GmbH, during August, to the Arbeitsgemeinschaft Brown Boveri Co. (BBC)/Krupp for a 15 MW high temperature research reactor. It will be built at Jülich in North Rhine-Westphalia and used by AVR in the interests of twelve state and commercial electricity producers to evaluate this type of reactor's power potentialities. Particular attention will be paid to the heat transfer efficiency, the economics of using natural uranium and the absence of excess reactivity inherent in this type of reactor design. Although no construction schedule is yet available, this project does mean that Germany will have its own facility as well as joining in the Dragon project for high temperature research.

US IN MIDDLE EAST. Near Rishon le Zion, AMF Atomics is constructing the first Israeli 1 MW research reactor and it is expected to be critical by the end of this year

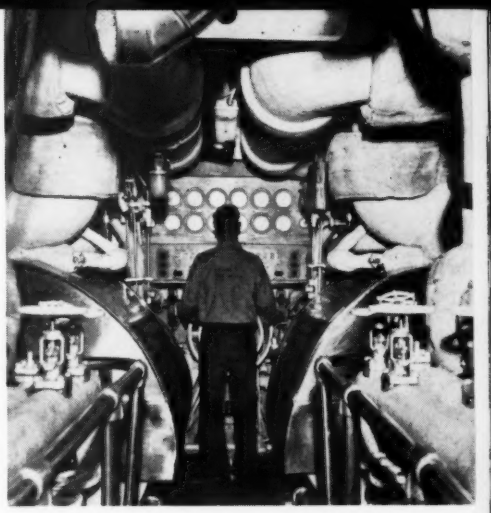
AEC to try for economic PWR

Washington, DC—The AEC has invited proposals from industry for participation in the Commission's Power Demonstration Reactor Programme. The major objective is the development of a small-sized pressurized water reactor plant that will economically generate approximately 60 MW/t and 16½ MWe. The fuel elements are to use slightly enriched, not more than 10% U-235, uranium oxide clad in zircaloy-2 or stainless steel and the design is to be based upon an average exposure of 10,000 MWD/t uranium or better. The incorporation of fossil-fuelled superheating to raise the electrical capacity to 22 MWe is at the option of the proposer. AEC hope that field construction of the selected design can start by about May 1960 and completion effected within the following two years.

The Commission will meet, as a maximum, the cost of the design, fabrication and installation of all the reactor portions of the power plant; industry will have to finance the rest of the necessary services to integrate the reactor system into a complete generating facility.

No take-off yet

Washington, DC—With major differences existing between the authorities concerned—some wanting early flight trials of existing nuclear plants and others wanting further advanced plants—not only has no target date been set for the aircraft propulsion programme but the US Air Force has not yet found a specific use for a nuclear powered aircraft. Despite this situation, the Congressional Joint Committee on Atomic Energy have indicated that up to 1958 some $M681·3 had been spent on the manned aircraft programme and that by the end of the 1960 financial year, the total would grow to some $M990. Since 1946 when the project was started, the costs, in millions of dollars, have been:—



INSIDE THE 'SKIPJACK.' The control deck above the reactor of the American nuclear submarine which recently visited the UK and then went on to La Spezia, the Italian naval base

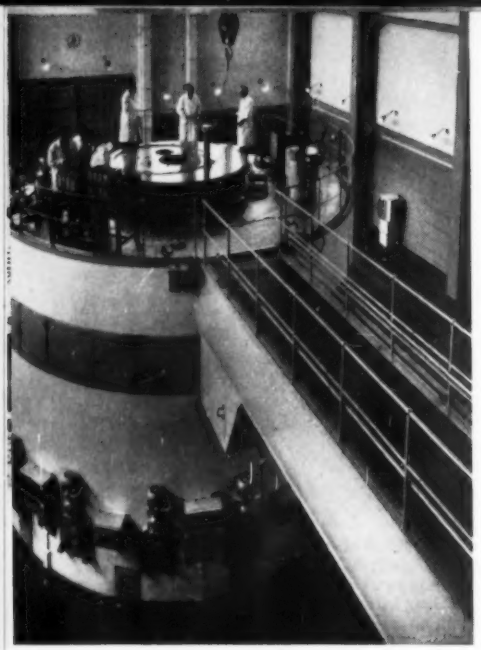
	OPERATIONS	FACILITIES	ANNUAL TOTAL	CUMULATIVE TOTAL
1946	1·3		1·3	1·3
1947	2·0		2·0	3·3
1948	6·2		6·2	9·5
1949	6·9		6·9	16·4
1950	6·7		6·7	23·1
1951	8·3	0·5	8·8	31·9
1952	20·7	6·2	26·9	58·8
1953	40·6	18·6	59·2	118·0
1954	21·5	3·3	24·8	142·8
1955	46·8	7·1	53·9	196·7
1956	96·8	60·4	157·2	353·9
1957	141·0	45·0	186·0	539·9
1958	130·0	11·4	141·4	681·3
1959 (estimated)	139·7	19·2	158·9	840·2
1960 (estimated)	143·4	7.0	150·4	990·6

The present policy of drift and indecision, despite the vast sums involved, will it seems be continued at least for some little time to come.

Breeders oust liquid fuel

Oak Ridge, Tenn.—The United States AEC have initiated a long term project to develop effective thermal breeder reactors which would fully use thorium's latent energy. Known as the Thermal Breeder Reactor Programme, it will aim at converting thorium to fissionable material at a doubling time of not more than twenty-five years.

This programme will modify the work now in hand on the fluid fuel reactors—the liquid metal fuel reactor, LMFR, the aqueous homogeneous, AHR, and the molten salt reactor, MSR, concepts. During the coming year, research and development on these projects will not be con-



WORKING TOWARDS POWER. The Hungarian 2 MW Soviet-type WWR-Z reactor at Czilieberg, is now being used in studies for future nuclear power stations

tinued except where applicable to the new project. There now seems to be little incentive for further development of fluid fuel reactors as a means of achieving low cost nuclear power in the near future.

In the initial stages, work on the new project will be directed to basic research and will include an evaluation to determine the type of breeder reactor having the greatest potential for continued long range development. This work echoes activities of the AEA, which is expediting the Dounreay Breeder (see comments of the Select Committee on Estimates, this month).

Intercontinental development

Brussels—Last month the US-Euratom

TAKING SHAPE. While progress is inclined to be slow at Latina, the laying of the reactor foundations has commenced. The turbine house will be located to the right of the reactor

Worldview

Joint Research and Development Board awarded its first three contracts, totalling approximately $315,000. The first contract was with the Battelle Memorial Institute for the study of heat transfer and vapour conditions as they occur in light water and in organic liquids, both of which may be used as coolants and moderators in reactors. A high pressure heat-transfer loop will be used during the study to simulate actual heat and boiling conditions in a reactor.

The French organization, Compagnie Industrielle des Céramiques Electroniques, have received a contract to cover a study project on the extrusion of uranium oxide.

The third contract is with the Advanced Technology Laboratories, a division of American-Standard, and is for a programme aimed at substantially reducing the costs of nuclear fuel through the application of high temperature spray techniques to form clad ceramic fuel elements. These laboratories are also engaged on two research programmes for the US Atomic Energy Commission—one provides for the evaluation and testing of the variable moderator reactor concept in which control is achieved by the adjustment of the level of ordinary water used as a neutron moderator, instead of mechanical manipulation of neutron-absorbing control rods. As the subject of a sub-contract, the core will be tested in its critical stage at the Battelle Memorial Institute.

The other AEC contract American-Standard has is for the improvement of the irradiation stability of natural uranium metal. It is expected that this will result in techniques for treating uranium that will materially increase the life of reactor fuel elements.

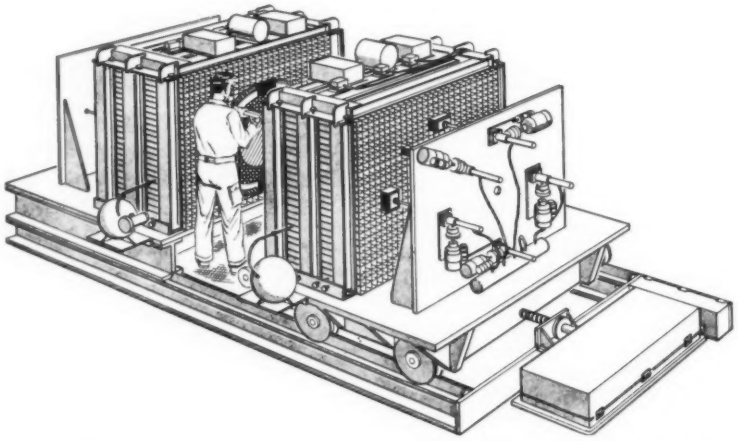
The US-Euratom Joint Research and Development Board is continuing its review of over 200 proposals from American and European organizations and additional contracts will be issued in due course.

More industrial participation

Vienna—The IAEA has received its first research contract from the United States AEC, valued at $20,000, for research on the production of calcium 47, which is at present in short supply and aims at a cheaper method of enriching calcium 46.

Pittsburg, Pa.—Westinghouse Electric Corp. are setting up an astronuclear laboratory here, for the development of nuclear power for outer space propulsion.

San Ramon, Calif.—Aerojet General Nucleonics have received a contract for a nine-month's study of a new power reactor concept—the proposed system is to be cooled by boiling sulphur at about 1200°F. High thermal efficiency is theoretically attainable but serious engineering problems must be solved. The study is to determine the practicability of this advanced design.



REACTOR CORE MOCK-UP. A critical assembly machine used in determining the core design of the US Southwest Atomic Energy Associates' Advanced Epithermal Thorium Reactor (AETR), in which the fuel will be a thorium-uranium alloy, sodium the coolant and beryllium or graphite the moderator

Washington, DC—A $127,000 research and development contract has been awarded to the Martin Co. by the US Navy to study airframe designs for a nuclear powered anti-submarine seaplane. These studies will concentrate primary attention on propulsion work developing an indirect cycle engine.

Washington, DC—Selected from among eleven submitted, the Babcock & Wilcox proposal to provide AEC with test irradiation services in a 60 MWt water cooled and moderated reactor, to be built at Lynchburg, Va., has been chosen for contract negotiations. It is estimated that it will take two years to build, would provide irradiation services for five years.

SELECT COMMITTEE REPORTS ON AEA

THE INQUIRY into the Atomic Energy Authority's Industrial Group (now divided into the production group and the development and engineering group) held by the Select Committee on Estimates has been completed. Sub-committees studied all previous literature including Annual Reports and White Papers, visited AEA establishments and interviewed senior men in the Authority and industry. The aim was to find out whether the policies and organization of the Industrial Group were being carried out in the way most fitted to get the best return for the money invested. The general tone of the report is favourable and records the Committee's impression that the AEA has carried out its tasks with efficiency and success.

Organization

The division of the old Industrial Group into two as from last July was examined in detail and approved. The Committee reports that in 1959-60 about a quarter of the two groups' research manpower and expenditure will still be employed in relation to the Magnox reactors, about a fifth on the AGR, and about a tenth on the problems of the fast reactor. It expressed surprise at the high proportion still devoted to the Magnox stations and the low priority of the Dounreay programme. The difficulties experienced by the Authority in recruiting men for this and other projects was commented on, 'The indications are that the group has planned in the past to do more development work than the available manpower has permitted'. Scientific staff just above the £2,000 a year level and senior men earning over £3,000 a year are the most difficult to find.

Development of reactors

The estimated generating costs of the first commercial nuclear power station have risen to 0·7d a unit or perhaps a little higher; thus, the Committee emphasizes the cost of electricity generation in these could be nearly 40% higher than that from well sited modern conventional stations working on base load. Some reductions in the price of uranium might lower generating costs by about 10%, but in any case 'The operation of these stations even if at present uneconomical is essential in order to produce the plutonium for bringing fast reactors into commercial operation. These could generate at between 0·3d and 0·4d per unit and achieve really cheap power in the 1970's.' Therefore 'The priority of the fast reactor should now be given special consideration. The future course of the nuclear power programme will be directly affected by the availability or otherwise of fast reactors in the early 1970's and its problems must be solved by 1966 at the latest.' Construction of a prototype should begin soon. The rate of progress of plutonium technology in relation to the fast reactor is also 'most important'. The report expressed its satisfaction that the whole plutonium technology research programme is to be stepped up.

Production and costs

The fuel element fabrication lines being built at Springfields for the first five civil stations will produce at a rate of about 3,000 tons a year when fully in production 'This should be adequate till 1964' the Committee thought, but the Authority should then hold talks with industry and CEGB to examine seriously the possibility of fuel elements being fabricated outside the Authority. Competition might then bring down the production costs.

The production of plutonium rose by 76·5% in the last three years and the works costs per unit of plutonium produced fell by 35%. The Committee reveals that this cost is about equally distributed between production of fuel elements at Springfields, irradiation in reactors (including handling fuel elements in cooling ponds) and chemical processing at Windscale.

At Capenhurst the cost of producing enriched uranium has decreased—the index cost fell by over 20% in the last three years.

The level of uranium stocks was considered excessive and the committee noted that the AEA is paying an unnecessarily high price for uranium because it is still held by contracts fixed some years ago.

The Authority's system of financial control was found to be generally effective except in relation to the Dounreay establishment where inadequate control 'has cost £500,000'. The estimate has been raised three times in four years and now runs at 38% over the original. The Report also found the lack of increase in the proportion of contracts put out to competitive tender over the last year was a 'real disappointment.'

Partnership with industry

The Committee reported that in 1958-9 only 8% of the Group's operating expenditure on research and development was accounted for by contracts with industry and universities. They 'believe that a change is now required' and endorse the Authority's plans to treble the amount of work placed with industry in the next few years (it is hoped that the value of the research done by industry for the Dounreay Establishment will be increased tenfold in the next year). Three reasons given by the committee for an increase were (1) 'The proportion of the nation's nuclear engineering and scientific skill that the Authority can recruit is limited while the volume of work to be done is expanding'; (2) 'It would be wasteful to leave the nuclear engineering industry unemployed, as it is today'; (3) 'Industry should take on more work so that it may more quickly acquire the ability to originate and exploit nuclear development itself'.

Main recommendations were:

1. The research and development of the Group which is directed to achieving improvements in the operating performance of the Magnox reactors should wherever possible be confined to those problems that the CEGB and the Consortia are not equipped to deal with.
2. The AEA should invite the consortia to attach a limited number of people to experimental reactor projects, or to join in technical discussions as soon as feasibility studies are complete. They should take positive steps to keep the consortia fully informed of the work on such projects and should consider seconding a few AEA engineers to the consortia to act as team leaders on design contracts. The committee reports that up to now the AEA do not appear to encourage the consortia to learn about a system at an earlier stage than the prototype. In particular there is no one from industry attached to Dounreay and 'no positive steps' have been taken to keep the consortia in touch with progress and thinking on the fast reactor, beyond the normal publication of papers and reports.

The committee considered whether the consortia should be given contracts for the development of whole reactor systems, but were doubtful if this could be done immediately, though 'this judgement may have to be qualified in respect of smaller reactors for export and marine purposes'. The Authority witnesses opposed the idea of a complete reactor contract for industry on the grounds that (a) it might lead to a spreading of effort over individual, uncoordinated projects (b) the Authority would be obliged to provide at least irradiation and fuel element services, and they have none to spare (c) the consortia do not yet have experience in commissioning and operating new reactor systems.

Royalty payments

The Atomic Energy Authority receive by way of royalties about 10% of the value of the nuclear part of the station or about £5 per kW installed. Commenting that receipts on a 500 MW station would be about £M2½ the report warned that to drive too hard a bargain by raising royalty charges any further would be 'shortsighted and detrimental to the commercial prospects of industry'.

What is the effect of efficiency on capital cost? Does taking interest payable on capital during construction into account make a significant difference to power costs? These are some of the questions answered in this new study

The Economics of Gas Cooled Reactors

by G. S. VINCENT, M.S., A.M.I.E.E., A.M.I.Mech.E.
Babcock & Wilcox, Ltd.

THE PRIMARY DECIDING FACTOR in economic consideration of a power plant is its effect on unit cost of electricity; the other important factor is the capital cost. In this exercise the variability of unit cost for different capital values, taking into account the variability of factors built into the unit cost calculation, e.g. efficiency, load factor, interest rate, has been considered. In doing this, factors which may normally be ignored have to be reconsidered to ensure that they can be ignored over a range of values and to determine the extent of any error that may be introduced.

A typical question which is raised and which this study will help to solve is 'What is the effect of efficiency on capital cost?' or, alternatively stated, 'If efficiency is increased how much can capital cost be increased for it still to be worthwhile.' We know the value of increased efficiency if the capital cost is the same, but what is the quantitative limit, at the expense of capital? Considerations of efficiency will also affect the curve of capital cost in £/kW against station size. This is usually drawn as a single line but strictly speaking there is a range of capital cost value for a given size. Whether this range is significant is to be determined and will be shown later.

Examination of unit cost calculations

The following nomenclature will be used:

A = factor for interest charges on capital during construction
B = factor for amortization charges on capital
C = capital cost in £M
D = burnup rate MWD/t
E = fuel rating in kW/t
F = load factor
G = capital cost in £/kW
H = heat output of reactor in MW
η = efficiency = MWso/MWt
I = interest rate
J = credit for plutonium in fuel
K = factor for capital and interest charges on fuel

No. of units sent out per year = $H\eta$ F.365.24.10^3

Unit cost has the following components:

1. Capital charge This is based on the capital cost of the plant and is assessed from the interest rate and amortization period. It is expressed as a fraction of the total capital cost. Interest charges are accrued on the cost of a plant because of payments during construction. No return is then being obtained for the capital paid out and these interest charges therefore have the effect of increasing the capital costs of a station. They can be assessed when the terms of payment are known and can be taken into account by introducing a factor by which the capital cost is multiplied. This cost has not generally been considered in most unit cost calculations.

Capital cost component of unit cost

$$= \frac{C.AB.240.10^6}{\text{No. of units sent out per year}}$$

$$= \frac{C.AB.240.10^6}{H\eta F.365.24.10^3} \quad \text{d}$$

$$= 27{\cdot}38\,\frac{C\,A\,B}{H\,\eta\,F} \quad \text{d}$$

The factor A can be calculated by considering each payment as a single payment and applying the compound interest factor for the interest rate and the time between the payment of the sum and the completion of construction. B can be read from compound interest tables for the appropriate interest rate and amortization period. C will be known and H, η and F specified.

2. Capital charge on fuel This cost will be in two parts due to the credit value of the fuel. Assuming that the fuel is expended by the time the life of the reactor is complete, it can be calculated by depreciating with interest charges the difference between the initial cost and the credit value over the life of the plant, and charging interest on the credit value of the fuel.

This cost will be dependent upon the inventory of fuel per MW of heat and is normally expressed in MW/tonne of fuel. For all the stations being built this figure has been of the same order and has been approximately 2·63 MW/tonne. Should this rating be decreased the charge will be increased in proportion by an amount equal to 0·003d per unit per 0·1 MW/tonne decrease in the fuel rating.

In addition to the fuel in the core, the capital value of new and irradiated fuel held in store must be considered. About three months' supply of fuel will come into each

category. Taking the value of irradiated fuel as the plutonium credit figure, the total value of the fuel held in store is approximately 8% of the initial value of the fuel in the core. The capital charge on fuel is increased by this factor to take these charges into account. The addition to the unit cost due to the additional 8% for fuel in store is in the order of 0·006d; therefore the error due to expected variances in the 8% will be of a second order of smallness and may be neglected.

This cost is also influenced by the credit value of the fuel. It was therefore calculated for values of £5000 and £3500 per tonne for the range of interest rates and life of plant considered. The maximum difference between the two results was in the order of 0·002d per unit. This is considered negligible, so for convenience a constant credit value is considered for this part of the unit cost.

The annual cost of the two parts of the capital charge on fuel can be expressed as:

initial value of fuel in core. K. 1·08

The factors influencing the relationship between capital and unit costs are investigated and formulæ derived for the capital cost, fuel replacement, and operational cost components of the cost per unit. Families of curves are constructed to show the effect of varying different parameters and a fresh comparison made of generating costs from nuclear and conventional stations

where $$K = B\left(1 - \frac{J}{20{,}000}\right) + I\frac{J}{20{,}000}$$

This expression represents the two parts of the capital charge as described, for one tonne of fuel.

For a constant credit value $J =$ £5000 and $K =$ 0·75B + 0·25 I

Thus capital charge on fuel $$= \frac{KH.20{,}000.240.1{\cdot}08 \text{ d/unit}}{2{\cdot}63H\eta F.8770.10^3}$$

$$= \frac{0{\cdot}2255\,K}{\eta F} \text{ d/unit}$$

(based on initial fuel cost of £20,000/tonne)

3. Fuel replacement costs This cost is assessed directly from the heat output of the core and burnup rate of the fuel. The burnup is taken as 3000 MWd/t and the fuel replacement cost will naturally be inversely proportional to the burnup.

The credit value of the fuel has a significant influence on this cost which is proportional to the difference between the purchase price and credit value. Should the effective credit value be reduced from £5000/tonne to £3500/tonne, this fuel cost will be increased by 10% and for fuel costs in the order of 0·15d to 0·20d per unit this possible increase must be considered. The replacement cost is also influenced by transport costs of the fuel.

$$\text{Fuel replacement costs} = \frac{H.365.F\,(20{,}000 - J).240}{D.8{\cdot}77.10^6.\eta FH}$$

$$= \frac{(20{,}000 - J)}{D\eta.102}$$

Assuming $J =$ £5000/tonne, $D = 3000$ MWd/t

$$\text{Fuel replacement costs} = \frac{0{\cdot}05}{\eta} \text{ d/unit}$$

4. Operational costs This cost covers personnel and maintenance costs and it is expected that these will be in the order of 0·05d per unit. It will vary with the load factor and will be expressed as follows:

$$\text{Operational costs} = \frac{0{\cdot}0375}{F}\text{d/unit for 0·75 LF}$$

5. Total unit cost Assembling all the previous cost items together we get the folowing:—

$$\text{Unit cost} = 27{\cdot}38\frac{C\,A\,B}{H\,\eta\,F} + \frac{0{\cdot}2255K}{\eta\,F} + \frac{0{\cdot}05}{\eta} + \frac{0{\cdot}0375}{F}\text{d}$$

Capital cost C and H are associated with stations of a particular size. It is more useful to use the comparative capital cost basis of £/kW which has wider applications.

$$\text{£/kW} = \frac{C\,10^6}{H\ \eta\,10^3} = G \qquad \therefore\ G = \frac{C\,10^3}{H\,\eta}$$

Thus unit cost in pence

$$= \frac{27{\cdot}38\,A\,B\,G\,10^{-3}}{F} + \frac{0{\cdot}2255K}{\eta\,F} + \frac{0{\cdot}05}{\eta} + \frac{0{\cdot}0375}{F}$$

Development of curves

1. A, B, and K are assessed knowing the interest rate and amortization period. Thus for a given value of load factor F, curves can be drawn of unit cost against G for a combination of values of interest rate, amortization period, and efficiency. Families of these curves will show the trend of the costs.

The interest rate is normally specified. To avoid confusion, curves for each interest value are drawn on separate sheets; the effect of varying interest rate can be observed by comparing points on different sheets.

To give a representative coverage to the variations likely to be experienced the following values were selected:

interest rates I: 5, 6 and 7%; amortization period: 15, 20, and 25 years; load factor: 0·75.

2. For the purpose of calculating the interest charges during construction the following terms of payment were used:

4½ year construction period, 10% down, 10% in eight half-yearly intervals, 5% at commissioning, 5% six months after. These values give the following:

Interest rate:	5%	6%	7%
Factor A:	1·1192	1·1451	1·1725

It is noted at this stage that these charges are very considerable.

Value of B for varying interest rate and amortization period.

Interest rate	*15 years*	*20 years*	*25 years*
5%	0·0963	0·0802	0·0710
6%	0·1030	0·0872	0·0782
7%	0·1098	0·0944	0·0858

Graphs of unit cost are drawn using the above values in Figures 1–3. For each combination of amortization period and interest value, the lines representing different efficiencies are parallel to each other.

3. The unit costs given in Figures 1–3 have the interest during the construction period taken into account. Com-

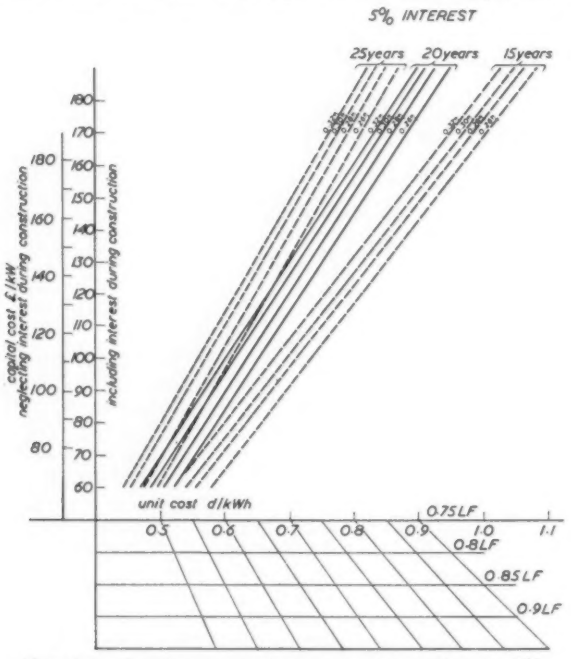
parison of these costs with the calculations where interest during construction is omitted can be made on the same graph by drawing a second £/kW scale in which the spacing has been reduced by a factor equal to A. Examination of the unit cost formula shows that is quite correct to do this.

The £/kW scale can now give both values directly and this is shown in Figures 1–3.

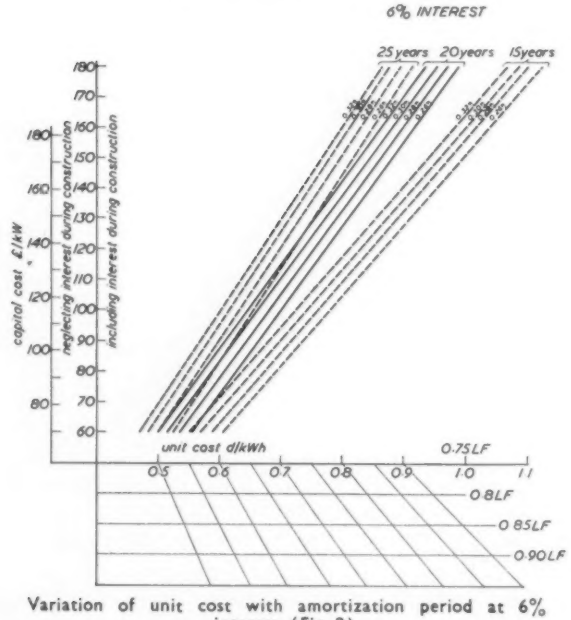
4. Examining the basic unit cost equation, it is seen that of the four component parts three are dependent upon load factor while the fuel replacement cost is dependent only on efficiency (assuming fixed replacement value and burnup). We can, therefore, from a point along the unit cost scale equal to the value of fuel replacement cost, draw a variable scale such that the unit cost can be read from it for different values of load factor.

The error over the range of values considered in using a single variable scale instead of one for each value of efficiency was only 0·002d. This is considered sufficiently small to ignore and Figures 1–3 have been drawn embodying this scale.

5. The components of unit cost are not each affected by all the variable quantities. Therefore graphs for each component can be simply drawn on one sheet and are shown on Figure 4; from these the component parts of the unit cost for any point on Figures 1–3 can be obtained.



Variation of unit cost with amortization period at 5% interest, showing the effect of taking into account interest during construction (Fig. 1)



Variation of unit cost with amortization period at 6% interest (Fig. 2)

Application of the graphs

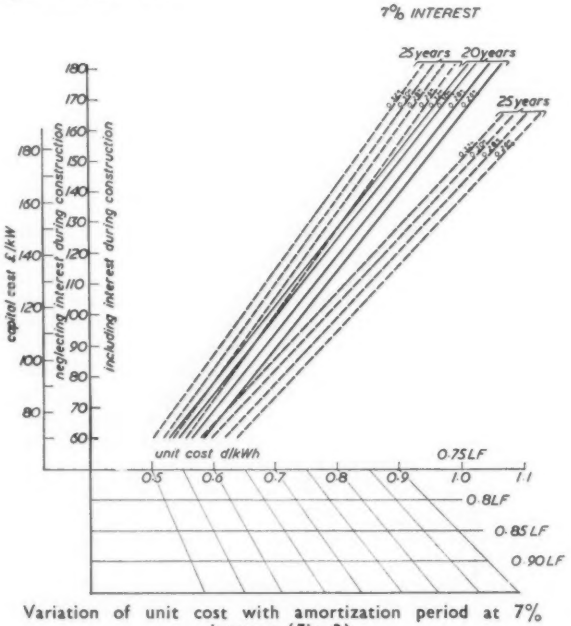
The following information can be obtained from the graphs subject to the variable quantities being within the range of values considered.

1. *The unit cost for any combination of capital cost, interest rate, amortization period, efficiency and load factor.* Taking the values given in Table I for the 500 MW station, capital cost £120/kW, 0·75 LF, 20 yr. life, 5% interest, and assuming 26% efficiency, a unit cost of 0·72d is read from Figure 1. This agrees with the upper figure quoted in Table I. Likewise for the 300 MW station at 6% interest a unit cost of 0·865d is obtained from Figure 2 compared with 0·87d in the Table.

2. *The component parts of the unit cost.*
Taking the values for the 500 MW station as above the following component costs are obtained from Figure 4.

Capital charge	0·392
Capital charge on fuel	0·085
Fuel cost	0·190
Operating cost	0·050
Total	0·717 d/unit

When the capital charges for the plant and the fuel are put together, the component costs and the total agree with figures in the Table.



Variation of unit cost with amortization period at 7% interest (Fig. 3)

Table I *Comparison of Generating Costs of Nuclear and Conventional Coal-fired Power Stations*
Revision of J. C. Duckworth's table (Geneva paper 1446) to include interest during construction. New and revised figures in bold

	NUCLEAR				COAL FIRED PLANT					
	COMPLETION DATE 1960/61		COMPLETION DATE 1962		LOW FUEL COST SITE				HIGH FUEL COST SITE	
					STATION NO. 1		STATION NO. 3		STATION NO. 2	
Ultimate station capacity	275–300 MWso		500 MWso		1000 MWi		1150 MWi		1000 MWi	
Generating set size					200 MWi		550 MWi 600 MWi		200 MWi	
Type of cooling	direct		direct		tower		tower		direct	
Year of commissioning first unit ..	1960		1962		1959		1963		1960	
Capital cost £/kWso (excluding initial fuel)	145		120		55		45		45	
Life of station	20 years		20 years		plant 25 years				building 40 years	
Load factor	75%		75%		75%		75%		75%	
Interest rate	5%	6%	5%	6%	5%	6%	5%	6%	5%	6%
Interest charges on capital during construction, %	**11·92**	**14·51**	**11·92**	**14·51**	**6·33**	**7·64**	**6·33**	**7·64**	**6·33**	**7·64**
Annual charge on capital, %	8·0	8·7	8·0	8·7	6·7	7·5	6·7	7·5	6·7	7·5
Effective annual charge on capital, % ..	**8·95**	**9·97**	**8·95**	**9·97**	**7·12**	**8·07**	**7·12**	**8·07**	**7·12**	**8·07**
Capital charges (including charges on initial fuel)	**0·55–0·56**	**0·61–0·62**	**0·47–0·48**	**0·52–0·53**	0·14	0·16	0·12	0·13	0·12	0·13
Fuel replacement charges	**0·17–0·19**	**0·17–0·19**	**0·17–0·19**	**0·17–0·19**	0·37	0·37	0·37	0·37	0·48	0·48
Works operating costs	0·06	0·06	0·05	0·05	0·05	0·05	0·05	0·05	0·05	0·05
TOTAL GENERATING COSTS d/u.s.o.	**0·78–0·81**	**0·84–0·87**	**0·69–0·72**	**0·74–0·77**	**0·56**	**0·58**	**0·54**	**0·55**	**0·65**	**0·66**
TOTAL GENERATING COSTS d/u.s.o.	0·70–0·77	0·74–0·81	0·59–0·66	0·63–0·70	0·56	0·57	0·53	0·54	0·64	0·65

3. *The capital cost to give a specific unit cost.*
Suppose a unit cost of 0·7d is required, the interest rate being 6% and the LF 0·75. Then, with a life of 20 years and an efficiency of 28%, the total capital cost will need to be £105/kW. This is a target capital figure and does not mean it can be obtained. The station size will have an influence on this possibility.

4. *The value of an improvement in efficiency.*
If the same example as item 3 above is taken except that the efficiency is 30%, then to obtain a unit cost of 0·7d the total capital cost can now rise to £110/kW. The difference of £5/kW is thus a measure of the value of an improvement in efficiency. The two capital costs, £105 at 0·28 η and £110 at 0·30 η, both giving the same unit cost, are thus equivalent capital costs.

5. *Comparison of capital costs of station designs at different efficiencies.*
This is done by comparing capital costs on the basis of the same efficiency. Equivalent capital costs for one or other of the stations may need to be obtained in a similar manner to item 4.

Take the case of the 500 MW station having a capital cost of £120/kW at 0·26 η and a hypothetical later design giving a capital cost of £110/kW at 0·28 η. The equivalent capital cost of the later design at 0·26 η is (from Figure 1) £105/kW. Thus there is an improvement of £15/kW.

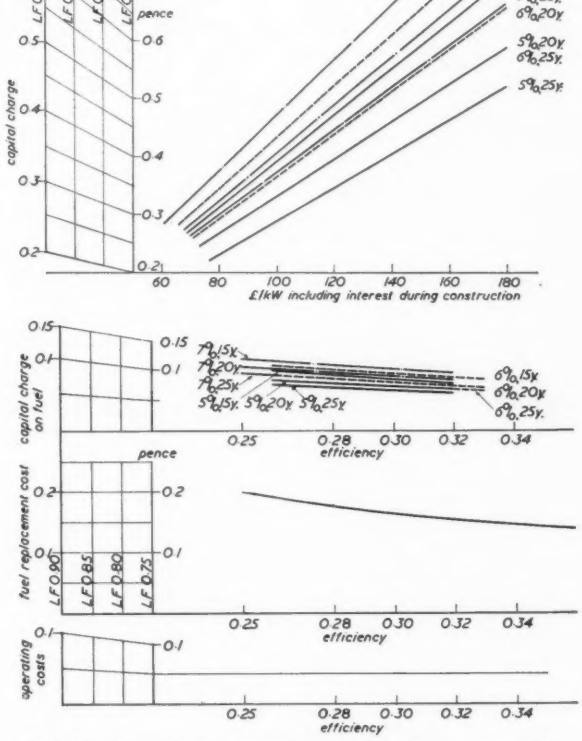
6. *Comparison of unit costs for the same capital cost, including and excluding the interest on capital during construction.*
Taking the values for the 300 MW nuclear station given in Table I for the interest rate of 5%, then from Figure 1, reading for the capital cost of £145/kW from each of the two vertical scales, we get the following two unit cost figures:

a. 0·802d including the interest charges.
b. 0·752d without the interest charges.

These figures agree with the comparative figures given in Table I.

An allowance should be made to cover purchase expenses when assessing the total capital cost of a station. For stations bought by the CEGB, this seems to be in the order of £10/kW. This figure will vary from purchaser to purchaser, particularly if overseas countries are involved.

Adjustments may need to be made to the unit cost to take into account departures from the standard values of fuel rating, burnup, fuel-credit, and fuel transport costs. The allowance can be obtained from Table 2.



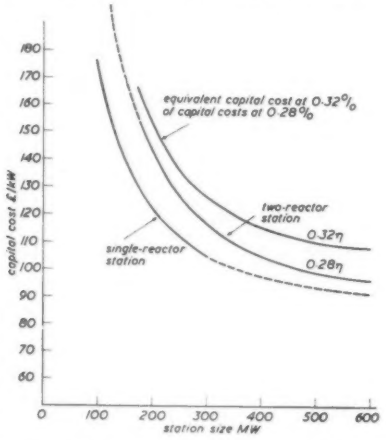
Relation between the component parts of unit cost and the variables on which they depend (Fig. 4)

Variation of capital cost with station size

A familiar curve is that of £/kW against station size. It has been shown that capital cost of a station can vary with different efficiencies and it is therefore only correct to draw this graph as a single line for stations of the same efficiency. The line will expand into a band when other efficiency values are taken into account and will appear as in Figure 5. The lines of 0·28 η have been drawn in line with the actual or expected capital cost of stations. The lines of 0·32 η have been derived from Figure 2 which means they are equivalent values for a station of 0·32 η. The actual value for a station of this efficiency may come

inside the band with the resultant saving in unit cost previously discussed.

It is also known that for a station of a given net output it is more expensive to have two reactors than a single reactor. On this basis, the curve of £/kW against station size should be for a station of the same number of reactors. Thus, any curve which joins together values of single and two-reactor stations does not give a true trend of costs with station size. A curve has been drawn in Figure 5 for single-reactor stations and its difference from that for two-reactor stations is clearly marked. This curve is again for a single efficiency of 0·28%; a range of capital



Variation of capital cost with station size at different efficiencies. These figures exclude the purchaser's capital expenses (Fig. 5)

values for different efficiencies would also be obtained. Where the curves are shown dotted, the trend is not substantiated by any actual information.

When Figure 5 is to be used to obtain a station size, the capital cost should be associated with an efficiency of 0·28 η. Capital cost in £/kW at other efficiencies should be converted to an equivalent £/kW at 0·28 η before the curve is used. Figures 1–3 are total costs and Figure 5 must be kept up to date with the latest capital costs. This curve has limited value as it is based on a standard site and civil costs can vary considerably with the site conditions.

Economic selection of station size

The curves in Figure 5 can be used together with the previous curves to give an indication of station net output to produce power at a given unit cost or to indicate the feasibility of doing so. The capital cost to give a specific unit cost, is obtained from the applicable graph. After reducing this capital value by an allowance for the purchaser's capital expenses, the net output of station can be read off from Figure 5. The resultant net output would be a marginal size. A larger station would yield an improvement over the specified conditions.

If the resultant purchase capital cost is below £95/kW it is unlikely that the specified conditions can be met: therefore they must be examined to see if any change is possible to allow a higher capital cost.

This curve may be used in the reverse manner to give an approximate unit cost for a given size of station.

Comparison of nuclear and conventional costs

In the Geneva paper (No. 1446) 'Economic aspects of the United Kingdom nuclear power programme' by J. C. Duckworth and E. Hywell Jones, a table was presented giving a comparison in generation costs between nuclear and coal-fired stations.

This table has been reproduced (Table 1), modified to take into account the interest on capital during construction. Taking a given burnup rate, efficiency and load factor, the fuel replacement costs should not vary more than 0·17–0·19d/u.s.o. Therefore, this range of values has been used to replace 0·13–0·19 given in the original table.

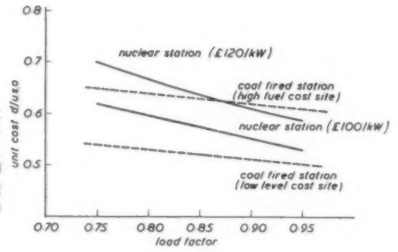
Standard conditions used for Figures 1–4 and allowances for variations

TABLE II

1.	Initial fuel cost	£20,000/tonne
2.	Plutonium credit value	£5000/tonne
	a. *Assumed to include transport costs*	
	b. *The fuel replacement cost is increased by 6·7% for each £1000 by which the credit value is reduced (approx 0·01d per £1000 reduction)*	
3.	Fuel burnup	£3000 MWd/tonne
	a. *A reduction of 0·005d per unit is obtained per 100 MWd/t increase in the burnup. This reduction is dependent on the initial fuel cost and the plutonium credit value remaining the same with increased burnup*	
4.	Heat rating of fuel	2·63 MW/tonne
	a. *The unit cost will increase by 0·003d per unit for each decrease of 0·1 MW/t in the fuel rating*	
5.	Fuel in store	8% of initial value of core
	a. *Based on 3 months supply of new and irradiated fuel*	
	b. *Irradiated fuel taken as plutonium credit value*	
6.	Operational costs	0·05d per unit at 0·75 L.F
7.	Construction time	4½ years
8.	Interest on capital during construction has been taken into account in the unit cost figures	
9.	£/kW scales are total figures and should include a sum for purchaser's engineering charges	

The same coal costs have been taken as in the original table. These are based on 73s a ton for a low fuel cost site and 93s a ton for a high fuel cost site. (11,000 B.t.u. per lb.). The construction period for a coal-fired station has been taken as 2½ years and payments have been spread over this period.

The increase in unit cost of the coal-fired station made by including interest on capital during construction is small and it indicates that no appreciable error was introduced by neglecting this factor. The increase in unit cost for a nuclear station is considerable and, when in the original table it lay between the unit cost of high and low fuel cost coal stations, the increase has now taken it above either, thus disturbing the competitive nature of the comparison.



Variation in unit cost with load factor assuming 5% interest and a 20 year life and using the values given in Table II (Fig. 6)

Taking a unit cost midway between that of a high fuel cost site and a low fuel cost site, a figure of 0·6d is obtained. This then should be the target for nuclear power costs.

It has been suggested that nuclear stations should be operated at higher load factors to bring the cost down. The cost of conventional power will also be reduced by this step and therefore, any comparison must be at the same load factor. Curves have been drawn in Figure 6 to demonstrate the effect of load factor on unit cost.

With the range of stations given in Table 1, it is seen that the nuclear stations (£120/kW) only become competitive with the high fuel cost coal station at a load factor of 0·87 which is unlikely to be obtained and gives a severe restriction on the application of nuclear stations. Figure 6 shows that it is necessary to come down to £100/kW for the specified conditions before the unit cost becomes competitive with a modern coal-fired station.

Under a new Act of Parliament, the first of its kind in the world, all nuclear installations will have to be licensed and inspected by the Ministry of Power

Licensing and insuring nuclear plant

by L. J. BLOM-COOPER, *Our Legal Correspondent*

WITH THE PASSING of the Nuclear Installations (Licensing and Insurance) Act, 1959, nuclear energy, harnessed for industrial and commercial power, has come of age. A forbidding title to an Act of Parliament, ushered in almost unnoticed in the closing stages of this Parliament, conceals a piece of legislation (the first of its kind in any country) which confers Parliamentary sanction to the Electricity Boards' programme of nuclear power stations and to the building of research stations by private industry.

Only land-based plant covered

The Act falls conveniently into three compartments: the licensing of all nuclear installations by the Minister of Power, compensation for those suffering damage to person and property from any ionizing radiations emitted from a nuclear installation, and a scheme of compulsory insurance to be adopted by those who become licensees of any nuclear installation. The legislation is concerned with nuclear 'sites' and therefore does not purport to cover any nuclear-propelled ship or aircraft. But the Government is not unaware of the impending possibility of the employment of nuclear power in these two fields, and, in view of the international character of ships and aircraft, is negotiating with other countries for a convention to control the future use of such ships and aircraft.

The Act has in mind primarily the licensing of the five nuclear power stations, now at various stages of construction, to be owned and operated by the CEGB and South of Scotland Electricity Generating Board; the Atomic Energy Authority is specifically included in the Act's operation, with modifications. It also contemplates that, increasingly, private industry will be building research reactors which similarly must be brought under Governmental supervision. Apart from nuclear reactors, the Act covers installations for the production, disposal or treatment of radioactive matter and may include establishments such as universities and hospitals. Although the Government does not intend that such institutions should be subject to the Act's provisions, it was found necessary to legislate broadly to cover in the future those cases where it is clear that the radioactive material will be present on a sufficient scale as to require licensing. Whether any hospital or university will require to be licensed has been left to the Minister to deal with by regulations which are subject to Parliamentary control.

The purpose of the Act is not to permit anyone to do anything but to stop him doing anything without proper supervision and licensing. This preventive aspect of the Act reinforces the powers which were given hurriedly, and without any idea of the future potentials of nuclear energy, to the Government under the Atomic Energy Act, 1946. The imperfections of control in that Act—no power to vary the terms of the licence or to control the licensee after his site had closed down—necessitated an entirely fresh start.

Army of inspectorate

Just as the safety of workers in factories has depended in large measure on the factory inspectorate set up under the Factories Act, 1937, so nuclear energy, in the interests of safety in the operation of reactors, will demand its own army of inspectorate. The Act vests the right to control all nuclear installations in the Minister of Power; it wisely avoids any details of the nature of conditions which may be attached to licences. The conditions are likely to be highly technical, advised on by the inspectorate and the Nuclear Advisory Safety Committee, and as such unsuitable for legislation. But a code of safety precautions will be devised by the inspectorate. Already the Government has appointed Major-General S. W. Joslin, previously Deputy Director (Personnel) of the AEA's Industrial Group, to become the first Chief Inspector of Nuclear Installations.

The one political aspect of the Bill, which produced the party wrangle in Committee stage in the Commons for four days, is contained in a harmless-looking provision that states that a licence may be granted only to a 'body corporate.' The Labour opposition sought to restrict the provision to 'statutory undertakings,' meaning only the Government institutions or nationalized Corporations. But this would have excluded the development of prototypes and the research work by private industry. The attack by Labour members on this provision led to the disclosure that Rolls Royce Ltd. were already making the fuel elements for nuclear submarines under contract from the Ministry of Defence.

The Minister of Power will have absolute control over the licensing system. He can order more or less stringent conditions to the licence and may if necessary revoke a licence. In this period of great activity in take-over bids the attempt was made to include a provision that a change in the control of a licensee company would operate as a revocation of the licence. The Government rejected the amendment but clearly indicated that any change in a company's directorate would cause the Minister to review the ability of those operating a licensed nuclear installation to fulfil the conditions of the licence.

Liability channelled to operator

Where prevention of nuclear accidents fails, the cure and remedy are provided in the Act in elaborate, and in parts ill-drafted, sections. It has become widely established in countries of Western Europe that liability for nuclear accidents must be an absolute one upon the operator. At the same time it has been thought highly convenient to channel this liability to one person—the operator of the reactor.

This fixing of liability on one person, the licensee under the Act, prevents the complication of a series of cross-actions to determine who is

liable for an accident, a frequent occurrence in the Law Courts in ordinary accident cases. And it greatly facilitates the establishment of adequate financial security by way of insurance. Certainly the insurance market would be greatly hampered, if not frustrated, in assessing the risks of several prospective assureds.

Insurance up to £M5 required

The licensee will be absolutely liable for injury to any person or damage to any property, wherever caused, from any ionizing radiations from the licensed site. The only exception to this liability is injury or damage attributable to 'hostile action in the course of armed conflict.' The licensee is obliged to provide security—in practice it will always be by way of insurance—up to an aggregate amount of £5 million for a period of ten years in respect of one installation. The amount of £5 million is not an actuarial calculation but the sum of money which the insurance market was prepared to carry as risk over ten years.

If the liability of a reactor owner exceeds £5 million there is no liability to meet the excess. That would be the sort of major national disaster the system of licensing and inspection is designed to make impossible. If such a disaster were to occur it would be a case in which it is customary for the Government to step in, comparable to the East coast floods of 1953.

The Act makes three concessions to a prospective claimant against a reactor owner. The claimant does not have to prove that the licensee, or anyone acting under his direction, has been negligent. That is the main effect of absolute liability: the licensee can however mitigate the extent of his damages so far as the claimant contributed to his own injuries. A person, moreover, may register with the Ministry that he was in any area at the time of a nuclear accident. The effect of registration is to put the burden of proving in any future claim that the claimant was not present in the area upon the licensee.

The most important concession is that the claimant will not have to present his claim within three years which is the statutory limit for all injury claims. During its passage through Parliament the time limit was changed from ten years (which is the time limit in the proposed OEEC Convention on third part liability) to thirty years. But where a claim is established which does not fall within the obligatory period of coverage, no payment need be made until Parliament has provided that the amount of the claim is to be reimbursed to the licensee.

Waste disposal and local authorities

The Act has also presaged further legislation in the field of nuclear energy in introducing local authorities to the licensing scheme in connexion with the disposal of radioactive waste. In any application for a licence the Minister may direct that notice of certain particulars be served on a local authority, a River Board, any local Fisheries Committee, or statutory water undertakings, but not on an electricity board operating a generating station. And the Minister may consider any representations from these organizations on the form of conditions to be attached to any licence.

Under the Atomic Energy Authority Act, 1954, the central Government was to be responsible for the disposal of radioactive waste for seven years, by which time the local authorities would be fit to take over this responsibility. A provision in the Act whereby local authorities are introduced to problems of waste will serve to interlock with legislation which will be required by 1961.

The tenor of the Act is clearly preventive in outlook. If in volume the Act's provisions are more concerned with cure and remedy, it is clear from the debates in Parliament that the legislators regard the establishment of a highly efficient inspectorate as the Act's prime purpose. The qualifications of inspectors for the field of nuclear energy will of necessity have to be of a high order. Whether such men are forthcoming is perhaps the outstanding problem of this fast-developing industry. The lack of numbers of highly qualified men was implicit in the Fleck Committee's report on the Windscale accident; the awaited report of a Committee under Sir Douglas Veale on the training requirements for nuclear health and safety staff is likely to be the key to the success which the Act clearly anticipates for the nuclear energy industry.

Organizing the new Inspectorate

DURING the next few months, a number of Orders in Council will be issued by the Government to bring the provisions of the Act into force. While this is the first time that nationalized undertakings and industry have been controlled by such a licensing system, a parallel system has existed for many years covering the manufacture and handling of explosive substances. The explosive regulations, under the authority of the Home Secretary, indicate the broad lines of control necessary and although Major General S. W. Joslin, the new chief of the Ministry of Power Inspectorate, is at present only reviewing the general policy covering his coming duties, he must be working on similar lines.

To set up a workable licensing system, it will be necessary not only to investigate the end product of any particular installation but to be kept fully informed right from its initial inception and consider the associated authorities involved.

The first fact to be established is that the operating body is financially substantial and either capable of holding adequate funds to comply with the Act or to finance necessary insurance.

The location of the installation is the next factor to be evaluated, when consideration will have to be given to the surrounding density of population against the nuclear power installed. At the same time, meteorological, hydrological and geological considerations will have to be taken into account.

The design details of the plant will have to be approved as incorporating all necessary practical safeguards by way of materials, fabrication and operating equipment.

When the radioactive material has been introduced into the installation, the inspectorate will have to ensure that proper equipment and techniques are employed at all times during handling and storage. Parallel with this, it will be necessary to ensure that adequate monitoring procedures are carried out.

With the establishment of relevant material and equipment specifications, to get 'a clean bill of health' from the inspectorate, personnel will become subject to control in that all operations will have to conform to a pattern approved by the Ministry concerned. In view of the long periods covered by liability under the Act, it will be essential that full detailed records are maintained and be readily available at all installations.

Already Major-General Joslin has visited the only privately-owned research reactor in the UK—Merlin—and, in due course, when the relevant Order in Council has been made, will be issuing an operating licence for it.

Following our recent articles on the principles, efficiency and applications of radiation detectors, we begin a new series on the associated electronic techniques

Electronics for radiation detection
1. Typical systems and pulse amplifiers

by K. KANDIAH, M.A., B.SC.
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1. INTRODUCTION

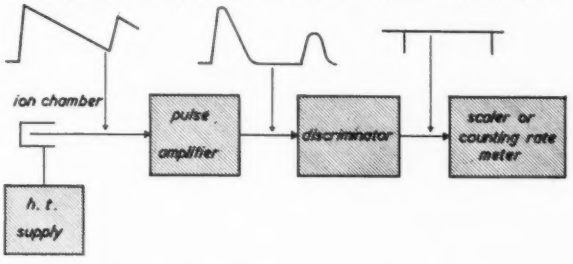
1.1 D.c. measurements

The mean current produced in a radiation detector is a measure of the incident flux. Strict proportionality between incident flux and current is maintained over many decades in ionization chambers and scintillation counters. The current in an ionization chamber is almost independent of the polarizing voltage applied to the chamber, provided that the voltage is high enough. In a scintillation counter, the current at the anode of the photomultiplier for a given photocathode current is proportional to V^n where V is the applied voltage and n is about 6 for most photomultipliers. Consequently, in this case the supply voltage should be stabilized to a high degree if an accurate measure of the flux is required. Finally a geiger counter can be used only over a limited range of flux, but proportionality is not maintained even over this range, owing to the long dead time after each discharge.

The mean current in scintillation counters is of the order of 10^{-7} A or greater so that no difficulty is encountered in the measurement of current. On the other hand, ionization chamber currents vary from about 10^{-6} A down to 10^{-14} A. Thus the measurement of small currents from ionization chambers presents many problems. Considerable precautions have to be taken in the manufacture and handling of all insulators associated with the collector of the chamber. The current is usually passed through a high value resistor and the voltage developed across it is measured by a d.c. amplifier in a feedback arrangement. The d.c. amplifier uses an electrometer valve in the input stage and when the current is of the order of 10^{-13} A or less it is preferable to use a vibrating reed electrometer. It is difficult to obtain high accuracy at low currents owing to zero drift in the d.c. amplifier and drifts in the value of the input resistor. At low currents the technique of measuring the voltage developed across a capacitor of known value when the current is allowed to flow for a fixed time is often employed. D.c. amplifier techniques and instruments have been described elsewhere (*1*, *2*).

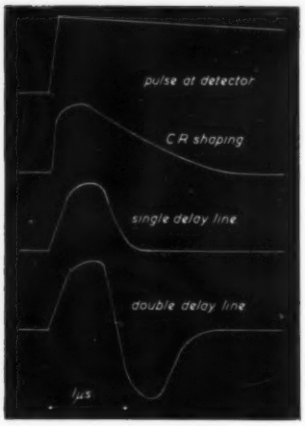
Measuring a radiation flux with a d.c. system involves relatively simple equipment and the normal operation of the equipment involves simple controls, such as range switches. Extremely compact portable instruments of this type to measure a wide range of flux can be manufactured, and the reliability of these instruments is of a high order, except at low currents when the accuracy deteriorates. An important advantage of a d.c. system is that it is possible to indicate a large range of flux on a logarithmic scale with a relatively simple amplifier. Such amplifiers are used extensively in health and reactor instruments.

Simple pulse counting system and associated pulse shapes (Fig. 1)



1.2 Pulse counting systems

Low intensities of radiation are measured with pulse counting systems. A pulse counting system overcomes the inaccuracy of d.c. systems at low intensities and enables the experimenter to eliminate unwanted pulses by the use of discriminators, single channel analysers and coincidence circuits. The simplest uses a geiger counter and a scaler or a counting rate meter. The pulses from some geiger counters are large enough to operate the more sensitive scaling circuits. It is, however, general practice to use a cathode follower or a quenching unit which reduces the counter voltage below the threshold for a predetermined time as soon as the counter produces a pulse. Non-self-quenching counters require a large resistive load and will not operate satisfactorily with most quenching units. This is due to the low impedance presented by the quenching unit and the finite probability of a counter discharge occurring during recovery time of the quenching circuit from a previous discharge. A quenching unit used with a self-quenching counter enables accurate corrections



Typical pulse shapes produced by three amplifier circuits (Fig. 2)

to be made for the dead-time of the system and reduces the extent of the discharge in the counter when the circuit is sensitive and fast, particularly with large counters, thus giving a useful increase in the life of the counter.

A simple counting system using an ionization chamber, a proportional counter, or a scintillation counter, requires a pulse amplifier and a pulse amplitude discriminator in addition to a scaler or counting rate meter, as shown in Figure 1. The pulse amplitudes from ionization chambers and proportional counters lie in the region of a few hundred microvolts to a few millivolts. The noise level referred to the input of the amplifier is not usually negligible, and hence the shape of the pulse at the output of the amplifier is determined by carefully chosen circuits. The discriminator is necessary to eliminate noise pulses and produce a standard output pulse for each signal pulse exceeding the threshold of the discriminator. The gain required in the amplifier depends on the amplitude of the pulses from the detector and the threshold level of the discriminator. Since threshold levels of about 100 mV are obtained with some of the recently developed discriminators, the voltage gain required is only about 10^3. The threshold level of other discriminators is better specified in terms of current input and in these cases a threshold of 100 μA is obtainable. The amplifier required in these cases should have a transconductance of a few hundred mA/V. Some of these discriminators will be described in a later article.

Pulse amplifiers for use with proportional counters and scintillation counters should have good gain stability and linearity, freedom from blocking on overload pulses and, in some applications, a very low noise level. Gain stability and linearity of better than 1% are usual requirements and this can be achieved by using negative feedback in valve or transistor amplifiers. The overload problem in an amplifier is somewhat more difficult to solve, particularly when the amplifier has to handle a high mean rate of pulses. Certain recent designs of amplifiers have good overload characteristics with a dead time of only a few microseconds after an overload pulse of a few hundred times the normal input. All problems on the amplifier are eased as the threshold level of the discriminator is reduced so that continuous effort is being devoted to the design of discriminators with low threshold levels and acceptable stability of threshold. The circuit and valve requirements for low noise amplifiers are well known and recent developments have made it possible to obtain consistent low noise performance from valve amplifiers.

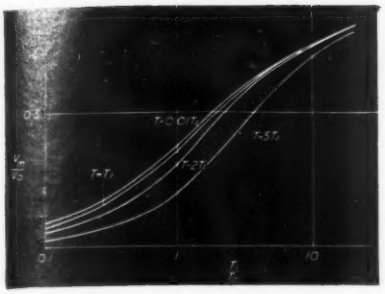
Transistor amplifiers do not provide the ultimate low noise performance obtainable with valves, although the development of special low level transistors may make it possible to use them in many amplifier applications. Transistor amplifiers can be used with scintillation counters since the signal pulses at the anode of a photomultiplier are rarely less than 10 mV.

1.3 Spectrometry

The simplest arrangement for the analysis of the pulse amplitude spectrum from a detector consists of a pulse amplifier, a single channel pulse amplitude analyser, and a scaler or counting rate meter. The single channel analyser produces a standard output pulse for each input pulse whose amplitude falls within two limits E and $E + \delta E$. The threshold level or bottom level E and the window width δE of the analyser are variable independently. In order to obtain the complete spectrum, the counting rate at the output of the analyser is plotted as a function of E with δE maintained constant. In order to obtain an undistorted spectrum, the mean rate at the input to the analyser should be quite low, particularly when a complex spectrum with closely spaced peak is being plotted. It is also necessary to use a window width δE much less than the width of the peaks and a scanning rate slow in relation to the time constant of the counting rate meter and recorder.

The use of a multichannel pulse amplitude analyser, which counts each accepted pulse in the channel appropriate to its amplitude, is often preferred. The time necessary to accumulate the counts over the spectrum to the same statistical accuracy as a single channel analyser is not always reduced by a factor N where N is the number of channels of the multichannel analyser. This is due to the fact that the dead time of a multichannel analyser is greater than that of a single channel analyser. In some of the multichannel analysers using amplitude-to-time conversion for channel selection, the dead time is greater than N times that of a single channel analyser. In these cases the improvement obtained by using a multichannel analyser is not necessarily due to the shorter time to accumulate a given number of counts. At moderate counting rates, particularly for measurements on short lived sources or particles from accelerators, it is essential to use a multichannel analyser to obtain the true spectrum.

The energy spectrum of heavy particles of known mass can also be measured by time-of-flight techniques. The spectrum of the time-of-flight over a fixed distance is recorded in a multichannel instrument by using standard timing pulses which are locked to a pulsed source of particles to select the various channels in turn. This technique can be used to measure times of



Pulse amplitude as a function of collection time and amplifier time constants (Fig. 3)

flight down to a few microseconds. For shorter times of flight, instruments of this type are difficult to design, since they require many high speed switching circuits. The alternative method is to generate a pulse whose amplitude is proportional to each time of flight and then analyse these pulses in a multichannel analyser. This type of instrument can only record one particle for each pulse from the source, but has the advantage that it can be used to analyse times of flight down to a few nanoseconds.

2. PULSE SHAPING

The use of correct shaping circuits plays a vital part in the determination of the nature of each particle which produces a pulse in the detector. *CR*, *LCR* or delay line circuits, whose values depend on the type of detector and the parameter of the particle of greatest interest, are used at suitable stages in the amplifier. Typical pulse shapes are shown in Figure 2. The collection time in normal ionization chambers is strongly dependent on the position of the track of the particle, and the use of a gridded chamber reduces this variation. Variations in collection time also occur in scintillation counters, particularly with large area photocathodes.

The normal practice is to use *CR* differentiating and integrating circuits because of their simplicity. The differentiating time constant T_1 is made about equal to the integrating time constant T_2 and each of these is made at least 3 times that of the collection time T of the detector. The use of differentiating time constants comparable to the collection time makes the pulse height dependent on the collection time (*3*). This is undesirable when strict proportionality between pulse height and particle energy is required. The stability of the values of T_1 and T_2 is important for precise measurements of energy, since a change in the value of T_1/T_2 by 10% causes a change in the amplitude of the pulse by greater than 1%, as seen in Figure 3, where V_0 and V_m are the amplitudes before and after shaping.

The use of delay lines for pulse shaping offers considerable advantages at high counting rates. The tail of the pulse falls off more rapidly with a delay line shaping circuit than with a *CR* circuit. It has been shown (*4*) that the resolving time of the delay line shaping circuit is about half that of a *CR* shaping circuit for a given value of integrating time constant T_2. Alternatively, for a given resolving time, the delay line system improves the signal-to-noise ratio for ion chamber applications by about 40%. The use of a double delay line shaping gives further improvements at high counting rates as described later.

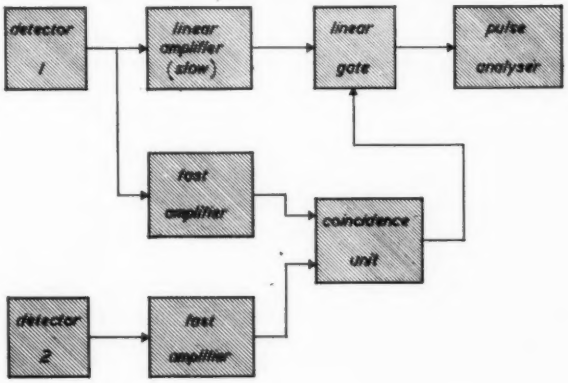
When it is necessary to determine the instant of entry of the particle in the detector, it is desirable to make the amplifier rise time shorter than the collection time in the detector. The upper cut-off frequency of the amplifier is then much higher than that necessary to give the best signal-to-noise ratio. When the time of arrival and the energy of the particle are to be determined with precision, it becomes necessary to use two parallel channels of amplification. Such parallel channels are often used in coincidence experiments, the block schematic of the arrangement being shown in Figure 4. This allows the analysis of the spectrum of those particles which fall on detector 1 at the same time as a particle incident on detector 2.

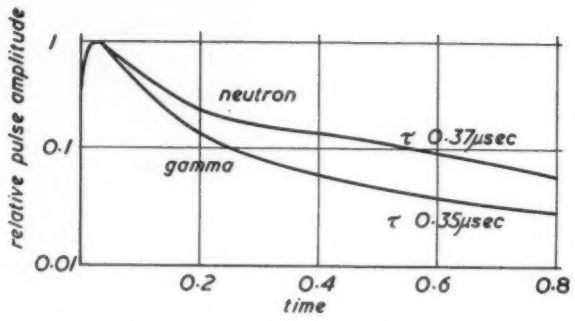
The shape of the light pulse from certain scintillators is characteristic of the type of radiation (*6*, *7*). The pulse shapes at the output of a fast photomultiplier looking at anthracene for gamma rays and neutrons are shown in Figure 5. The ratio of the slow component to the fast component is greater for neutrons and suitable shaping circuits can discriminate between gammas and neutrons. Two methods of discrimination may be used and the principles of one may be seen from the block schematic shown in Figure 6. A flat topped pulse whose height is proportional to the peak of the current pulse from the photomultiplier is compared with the integrated current pulse. With suitable values of gain in the amplifiers, the amplitude of the integrated pulse will be higher than the stretched pulse for neutrons and lower than the stretched pulse for gamma rays. The comparator will give an output at one of two terminals depending on the nature of the incident radiation. The second method of discrimination suggested by R. B. Owen (*6*) depends on saturation of the photomultiplier on the fast component which can be made to produce a negative pulse on the last dynode for gamma rays and a positive pulse for neutrons when the final anode voltage is kept at a low value.

3. PULSE AMPLIFIERS

The total voltage gain required in a complete pulse amplifier depends on the type of detector and on the

Pulse analysis with a coincidence gate (Fig. 4)





Neutron and gamma excited pulses in anthracene (Fig. 5)

threshold level of the discriminator or the analyser connected to the output of the amplifier. Most analysers and many of the earlier discriminators require input pulses in the region of 5 to 50 volts. The amplifier gain will then require to be about 100 or slightly greater for scintillation counters and about 10^6 for ionization chambers and some proportional counters. The total gain of 10^6 is usually obtained by using three amplifier sections, each providing a gain of about 100. The necessary pulse shaping circuits are placed between the sections. Each amplifier section has adequate feedback to obtain an overall gain stability of better than 1%. With the sensitive discriminators it is often unnecessary to use an amplifier for scintillation counters, and the shaping is then done in the anode circuit of the photomultipliers.

3.1 The ring of three amplifier

The circuit diagram of a widely used amplifier section (*8*) is shown in Figure 7. A fraction of the output voltage is fed back to the cathode of V_1 through the potential divider consisting of R_3 and R_4. In the absence of feedback the pulse rise time is limited by the stray capacitances at the anodes of V_1 and V_2, and the shorter of the coupling time constants will determine the droop on a long pulse. The main purpose of the negative feedback is to stabilize the gain against drifts in valve characteristics or power supplies. It can be shown that the gain bandwidth product obtained with this feedback amplifier is the same as that of an unfedback amplifier using V_1 and V_2, the main purpose of V_3 being to provide the necessary low impedance to the feedback circuits. The design is based on the knowledge that the rise time constant is approximately C_3R_3 and the gain is approximately equal to R_3/R_4. The value of R_4 should not be so high that it reduces the gain of V_1 but the value of $R_3 + R_4$ should not be so low that the gain of V_3 falls much below unity. Increasing the values of R_1 and R_2 will increase the loop gain and hence the gain stability, but an upper limit to these values is reached when the high loop gain produces an overshoot of the output pulse in response to a step input. C_1 is normally equal to C_2, assuming that V_1 and V_2 are almost identical and, in order to simplify the design, R_1 is made equal to R_2. In the final design of the amplifier, the following conditions will hold:

$$R_4 \ll 1/g$$
$$R_3 + R_4 \gg 1/g$$
$$A^1 = A/(1 + \beta A)$$
$$A = g^2R_1R_2$$

and $C_3R_3 = 2C_1R_1/[1 + 1\sqrt{(1 + \beta A)}]$

where g is the slope of each valve, A is the unfedback gain, A^1 is the fedback gain and $\beta = R_4/(R_3 + R_4)$.

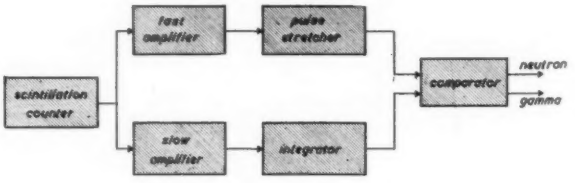
This amplifier has a low output impedance and excellent gain stability, almost up to the top cut-off frequency. In practice a gain of 100 with a bandwidth of 4 Mc/s can be obtained with CV138 valves. Owing to the complex nature of the output impedance the amplifier will oscillate at a high frequency if a large capacitance shunts the output. When feeding such a capacitive load, a resistance of about 100Ω is placed in series with the output.

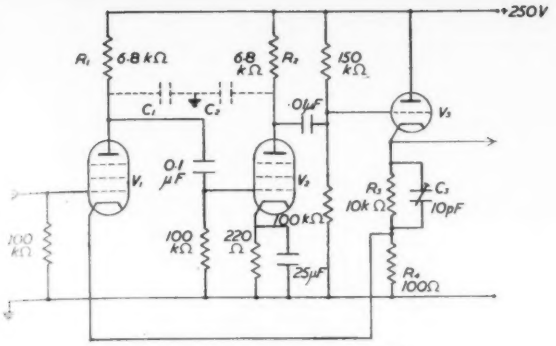
3.2 Transistor amplifiers

Transistors have been used very successfully in many circuits in pulse counting equipment. The use of transistors in pulse amplifiers presents many awkward problems. The first of these is that the use of transformers is precluded, since the amplifier itself must have a wide bandwidth when the effect of the pulse shaping circuits is ignored. Although wide band amplifiers using transformer coupling have been described (*9*), the frequency response curve of these amplifiers is not flat over the useful range and is strongly dependent on a number of parameters which cannot be controlled, with the result that the transient response will not satisfy the requirements for detectors except in limited applications.

The use of resistance coupled circuits can give satisfactory transient response but it involves the use of grounded emitter circuits. The cut-off frequency of such circuits is then very low so that it is necessary to use transistors with alpha cut-off frequencies in the region of 150 Mc/s or higher in order to obtain an overall bandwidth of a few Mc/s in the complete amplifier. The circuit of a current amplifier (*10*) which has been used with radiation detectors is shown in Figure 8. This amplifier gives a current gain of 11 with a bandwidth of about 10 Mc/s. Owing to the drift of operating conditions of transistors with temperature, it is necessary to apply a large d.c. feedback from the emitter of J_2 to the base of J_1. The medium frequency current gain is approximately equal to $\alpha_2(R_3 + R_5)/R_5$ where α_2 is the current gain of J_2. The output voltage from such amplifiers is limited to about 10 V and the current is limited to about 10 mA. This would necessitate the use of sensitive discriminators if the connexion between the

Pulse shape discrimination by comparing a flat-topped pulse proportional to the peak current with the integrated current pulse (Fig. 6)





Ring of three amplifier (Fig. 7)

amplifier and the discriminator is long, since a large part of the output power from the amplifier will be absorbed in the small resistor placed as a load across the connecting lead. A preferable technique is to build the discriminator in the same unit.

A transistor is highly non-linear when operated with a voltage input, since the relationship between collector current I_c and input voltage V_e is given by an expression of the form

$$I_c = \alpha I_{eo}(\exp\frac{eV_e}{KT} - 1) + I_{co}$$

where α is the current gain, I_{eo} and I_{co} are the emitter and collector junction reverse saturation currents, K is Boltzmann's constant, T is the junction temperature, and V_e is the emitter-base (input) voltage. Consequently a high degree of negative feedback is required when transistors are used as voltage amplifiers. This, combined with the low and variable input impedance, makes transistors unsuitable as voltage amplifiers when a high degree of linearity is required.

3.3 Sensitivity

The ultimate sensitivity that can be achieved with any radiation detector is governed by the magnitude of the fluctuations present either in the detector or in the amplifier. In the case of the scintillation counter, one limit is set by the presence of thermal emission from the photocathode. Although the noise pulses are due to single electrons emitted by the cathode, the statistical variations in multiplication make some of the noise pulses at the output equivalent to the pulse produced by two or more electrons multiplied by the average gain. Thus, scintillations which produce only a few photoelectrons are difficult to detect. Secondly the output pulse size has fluctuations due to the statistical variations in the number of photoelectrons produced by particles of a given energy. Improving the efficiency of the photocathode and the light collection from the scintillator therefore reduces the percentage fluctuations and thus improves the energy resolution.

The energy resolution obtained with ionization chambers depends solely on the noise level of the amplifier. There are three possible causes of noise in this case. The noise due to thermal agitation in the input circuit is strongly frequency dependent since the input circuit is equivalent to a shunt-CR combination. By making this time constant very long compared to the differentiating time constant in the amplifier, the noise due to the input circuit falls entirely outside the amplifier bandwidth and can therefore be neglected. The grid current of the first valve flowing into the input circuit and the fluctuations in anode current are the main causes of noise.

It can be shown (*11*) that the r.m.s. equivalent noise voltage V_g due to a grid current I_g is

$$V_g = \left(\frac{eI_g}{2C^2}\,\frac{T_1^2}{T_1+T_2}\right)^{\frac{1}{2}}$$

where C is the total capacitance across the input.

The r.m.s. noise voltage equipment V_s due to shot noise in a triode valve is

$$V_s = \left[\frac{2{\cdot}5KT}{g}\,\frac{T_1}{T_2(T_1+T_2)}\right]^{\frac{1}{2}}$$

where g is the slope of the valve.

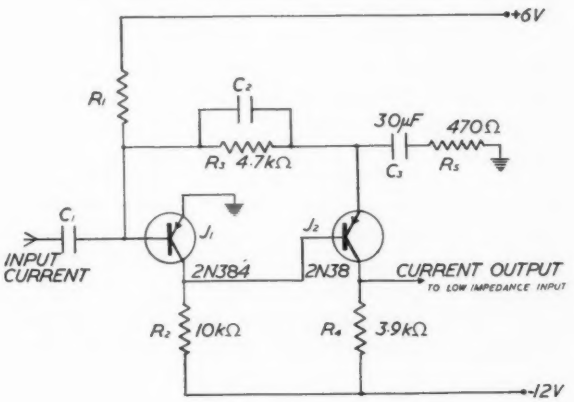
In the above expression T_1 and T_2 are the differentiating and integrating time constants in the amplifier. If we vary T_1 and T_2, maintaining $T_1 = T_2$, the grid current and shot noise for a given valve will vary as shown in Figure 9. The noise is referred to the equivalent number of ion pairs since this will give a direct figure for the energy resolution of the system. Hence, for a given grid current and slope the noise has a minimum value at a particular time constant T_0 given by

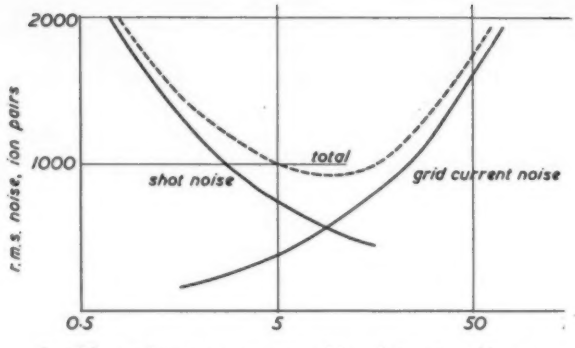
$$T_0^2 = \frac{5kTC^2}{geI_g}$$

It is seen that the time constant which gives minimum noise is a function of g and I_g. To a first approximation, g is proportional to $I_a^{1/3}$ and I_g is proportional to I_a where I_a is the anode current of the valve. Thus changing the anode current will change the point of the minimum. It should be understood that if the amplifier is required to be used with a given time constant the operating conditions of the valve which give the minimum noise may not correspond to a minimum of the total noise curve applicable to that set of conditions.

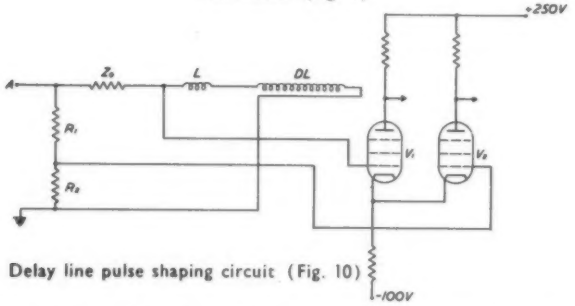
Transistor amplifiers introduce more noise than valve amplifiers. The mean square noise current in the collector circuit is proportional to the collector current and depends also on the impedance of the input circuits in a complex manner. In general the noise decreases as the collector current is decreased until a point is reached when the current gain of the transistor begins to drop off, when the noise referred to the base

Current pulse amplifier using transistors (Fig. 8)





Amplifier noise spectrum comprising shot and grid current noise (Fig. 9)



Delay line pulse shaping circuit (Fig. 10)

increases with decreasing current. This occurs at collector current of the order of 100 μA. Since the alpha cut off frequency f_α also depends on the collector current, the choice of optimum collector current is largely empirical. In general, transistors are about ten times worse than valves for these applications as far as noise is concerned.

3.4 Overload conditions

One of the biggest problems encountered in the use of amplifiers with proportional counters and scintillation counters is due to the large range of pulse amplitudes under certain conditions. If the interest is centred on the X-ray peaks in a scintillation counter, the largest pulses due to energetic gamma rays may well be 20 times greater. The large pulses will cause the charging up of coupling capacitors due to grid current in a valve amplifier or due to excessive base current in a transistor amplifier due to saturation. At the end of the large pulse the output will overswing and return to the base line with a long time constant. This will cause errors in the counts recorded, particularly if the pulses are being analysed. In the case of valve amplifiers some improvement is obtained by reversing the values of the anode load and the following grid leak. Thus the grid leak is made equal to 4·7 k Ω, say, while the anode load is made 22 k Ω or even larger in value. Under this condition the overswing voltage on the grid is reduced, partly because of the longer time constant of the process of charging the capacitor during the overload and partly because only a fraction of the voltage developed across the capacitor appears at the grid.

Two other factors introduce a distortion of the pulse amplitude spectrum. At high counting rates the mean level of single CR or delay line shaped pulses will vary according to the average rate immediately preceding any given instant. This shift of the base line at random will cause a broadening of the peaks and a downward shift. The overload pulses cause an unbalanced surge on the H.T. supplies which also causes broadening of the peaks. Two different approaches to this problem have provided considerable improvement in the performance of amplifiers. The first technique is to use amplifiers consisting entirely of long-tailed pairs with negative input and output pulses. This prevents grid current being drawn at any time and maintains a constant drain from the H.T. supply. The main disadvantage of the system is that there is only a small amount of feedback so that the gain stability is poor.

The second technique is to use a double delay line pulse shaping system. An amplifier using this principle (*5*) has been shown to handle pulse input rates of about 200 kc/s. Overload pulses due to Co-60 gamma rays at over 10 kc/s also caused no serious distortion of the low energy peak of 30 keV X-rays from a Cs-139 source. The pulse shaping is carried out by means of shorted delay lines of the HH 1500 type at two stages of the amplifier, one of which is shown in Figure 10.

There are two limitations of a simple pulse shaping circuit using a delay line. The output is usually loaded by a valve input capacity and a partial mismatch occurs. The purpose of the inductance in Figure 10 is to provide correct matching allowing for the input capacitance of V_1. The second limitation is due to the finite resistance of the delay line which produces a pedestal on the shaped pulse. This can be eliminated by feeding a fraction of the input signal at A through the potential divider R_1R_2 to the other grid of the long tailed pair amplifier. It is usually necessary to adjust the values of L and the attenuator R_1R_2 in order to obtain a good shape for the output pulse. In general, the choice of the correct position for the shaping circuit in a multisection amplifier is essential. Placing it too early in the amplifier will lead to excessive hum and noise from later stages, whereas if it is at a late stage pile up of pulses will lead to overloading of the earlier amplifier stages. The large pulses are prevented from drawing grid current by using catching diodes in such a way that current is drawn through the coupling capacitor in both directions, firstly on the positive part and later on the negative part of the double delay line shaped pulse.

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Soon to be required by law, routine personnel monitoring for workers has always been important, and the Radiological Protection Service has grown to an organization handling over 3000 films a week

How a film badge service operates

by J. F. B. DEALLER, B.Sc.
Radiological Protection Service

UNTIL THE LAST WAR the bulk of experience with radiation, its effects and dosimetry, was the prerogative of medical workers. The war however gave a fresh impetus to non-destructive testing and laid the basis for the radiation industry as we know it today. The ever increasing range of radiation sources available and the spread of knowledge of the properties of radiation has led engineers and physicists in industry to turn ever more frequently to radiation as a solution to their problems, not only in non-destructive testing, but also in process control, routine analysis and research. The nuclear reactor itself has now entered the general world of electrical power production. High energy machines with enormous radiation outputs have been developed and are being used in industrial processes. At the same time the electronics industry has produced a number of devices such as the klystron in which electrons are accelerated and then stopped. Fundamentally these devices are similar to X-ray tubes and many of them require shielding to reduce their X-ray output to an acceptable level.

Thus during the last two decades techniques involving radiation have spread to a large number of industries. Indeed, it may well be only a matter of time before every factory possesses a radiation source of some sort.

Maximum dose laid down

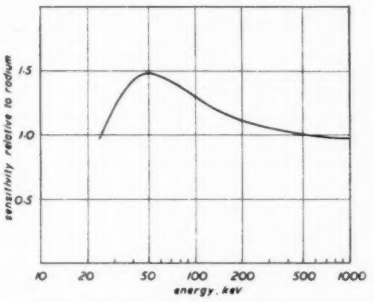
Recommendations on maximum permissible doses of ionizing radiation have been made over the years, initially by the British X-ray and Radium Protection Committee and later by the International Commission on Radiological Protection which works under the auspices of the International Congress of Radiology. As far as external radiation is concerned, these have, until recently, always taken the form of laying down a maximum permissible weekly dose. In 1959 new recommendations were published (*1*) which set a limit on the radiation dose which could be received during any period of 13 weeks. In the case of the blood-forming organs, the eyes and the gonads, maximum permissible doses are also laid down for long term exposures. These recommendations, summarized in Table 1, reduce the importance of the dose received in any particular week, but introduce a need to sum doses over a period. They also permit the whole of a quarter's dose to be received in a single week. This would, however, carry the penalty of 12 weeks complete freedom from radiation work; such a procedure could hardly be adopted regularly in an industrial process, although it could be appealed to in the case of an over-exposure.

Monitoring will soon be law

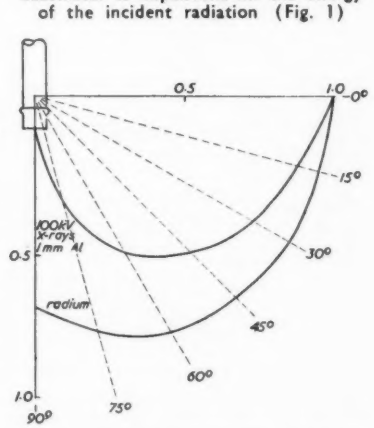
The original concepts of permitted doses were intended primarily for medical workers, but the levels laid down have been adopted by radiation workers in industry and their employers, radiation protection measures being applied on a voluntary basis on a very wide scale.

The ever increasing scope of radiation has caused a great deal of interest to be taken in problems of protection. One of the results of this interest has been the formulation of the current recommendations of the ICRP; another has been the decision of the Ministry of Labour (in common with similar Ministries in other countries) to put forward Special Regulations to control the use of ionizing radiations in industry (*2*). The Draft of these Regulations lays down dose levels which are largely similar to those proposed by ICRP.

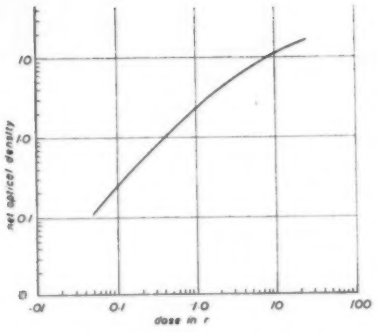
The recommendations of the ICRP explicity demand that the doses received by personnel during their work should be measured. The Draft Regulations explicitly call for this to be



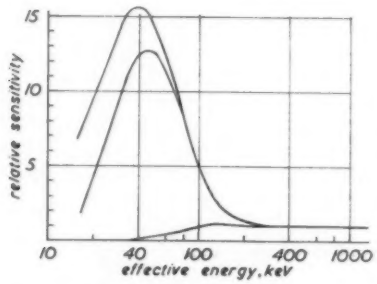
Sensitivity of a commercial quartz-fibre dosemeter is dependent on the energy of the incident radiation (Fig. 1)



Sensitivity also varies with the direction of radiation, shown here for 100 kV X-rays and radium gammas. Unit sensitivity is at $\theta = 0$ (Fig. 2)



Relation between dose and net optical density for a typical monitoring film, Ilford PM3 (Fig. 3)



Response of Ilford PM1 film to radiation of various energies relative to response to radium gammas. Upper curve: unshielded; middle: shielded with 0·035 in. Dural; lower: shielded with 0·04 in. tin (Fig. 4)

done and specifically state that the monitoring should be carried out using a 'suitable photographic film.' An 'appropriate and efficient' dosemeter is also to be worn where specially required (Regulation 11).

Thus radiation safety requires, and the law will soon demand, that workers exposed to radiation because of the nature of their work should have their doses continuously monitored.

TABLE 1 *Maximum permissible exposures to external radiation*

ORGAN	DOSE		
	13 weeks (rem)	*Year (rem)*	*Long Term† (rem)*
Gonads, blood-forming organs, lenses of the eyes	3	12	5(n-18)
Skin, thyroid gland	8	30	30(n-18)
Hands, forearms, feet, ankles	20	75	75(n-18)

† n is the age of the worker in years. It will be noted that these figures permit *average* weekly exposures of 100 mrem, 600 mrem and 1500 mrem for the three groups of organs.
For practical purposes in external radiation monitoring, doses measured in rads are numerically equal to the biological dose in rems, except for neutrons where the dose in rads must be multiplied by the relative biological efficiency.
(For these particles generally rems (neutron) = rads (neutron) × 10).

Instruments or film ?

The two dosemeters commonly used in personnel monitoring are the ionization chamber and the photographic film. The first depends upon the loss of charge by a condenser due to ionization of air between the electrodes and the second upon the actinic response of photographic emulsions to ionizing radiations.

At first sight the ionization chamber would appear to provide the best method of personnel monitoring. There are two types of ionization instrument: the fountain-pen quartz-fibre dosemeter and the pocket. In the former the dose received since the instrument was last charged can be read at a glance, while the dose received by a pocket ionization chamber can be found very quickly. This advantage has, indeed, led to their widespread adoption, particularly in processes such as gamma radiography where protection depends to a considerable extent upon 'time and motion.'

In common with all ionization chamber instruments, the commercial quartz fibre dosemeter has a response that depends upon the energy of the radiation and the direction of the source. Figure 1 shows the response of a typical instrument to radiation relative to its response to radium gamma radiation, and Figure 2 illustrates its directional dependence. It will be noted that the instrumental errors are not likely to be serious for energies greater than 120 keV. Instruments with a better performance are under development.

A more serious disadvantage of the ionization chamber is the transient nature of the reading. Once the chamber has been recharged there is no way of checking whether it had been read correctly.

All ionization chambers have a tendency to leak, particularly under the type of adverse conditions met with in industry. Whilst the recording of a dose which is too high is an error on the safe side, such errors could impair an individual's dose history and lead to unnecessary investigations. There is also an inclination to set down any apparently inexplicable dose as being due to a leak.

The range of the instrument is limited. A commonly used scale shows 0–500 mr in 20 mr steps, and such an instrument clearly cannot distinguish between 1 r and 10 r. Instruments with a wider range have too great a threshold and it is therefore necessary to wear two detectors at least in order to obtain reasonable coverage.

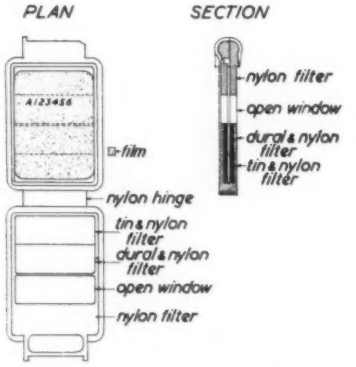
Photographic film has the serious disadvantage that the interpretation of the dose takes a considerable time. If it is done on the spot, the dose can be estimated in a matter of hours while a routine postal service should be able to deliver the results within a week. This latter time can, of course, be reduced greatly in an urgent case, but must inevitably exceed that taken to read an ionization dosemeter.

The film provides a permanent record of dose which can be referred to subsequently, while its range of response is very much wider than that of the ionization chamber. Figure 3 shows the relation between dose and net optical density for a typical monitoring film.

Design of the filter system

The response of the film is markedly dependent upon the energy of the radiation as is shown in Figure 4 (upper curve). This defect can however be overcome, and indeed turned to advantage, by the judicious use of filters incorporated into a film holder.

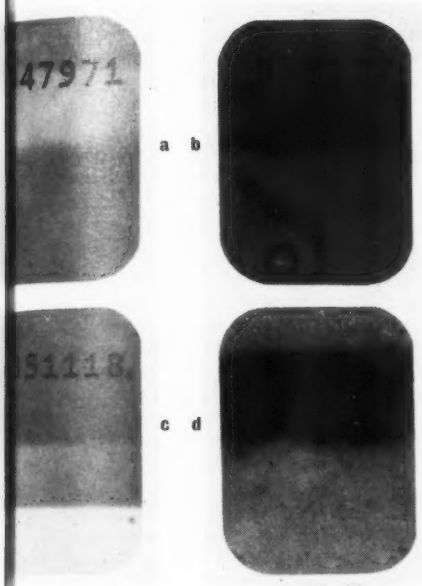
The design of the filter system depends upon the range of energies to which the film is to be exposed. The filter system in the holder designed by the Radiological Protection Service personnel monitoring service has



The film holder designed by the R.P.S. consists of a plastic case with two pairs of metal filters (Fig. 5)

been described in detail elsewhere (*3*). Essentially the film holder* (Figure 5) consists of a plastic case holding a dental size (but not dental emulsion) film. Mounted in the plastic are two pairs of metal filters, the lower pair being 0·040 in. tin and the upper pair 0·035 in. of BS-L72 duralumin. Part of the film is shielded with $\frac{1}{16}$ in. plastic and part is unshielded.

* Manufactured by Savage & Parsons Ltd., Watford Way, Watford



Examples of radiation monitoring films after a. primary gamma radiation b. primary gamma radiation with beta-particle contamination c. 200 kV X-rays d. beta and gamma radiation with 'spots' due to contamination by active material (Fig. 6)

The effect of the tin filter is to reduce the quantity of radiation in the 400 keV to 90 keV energy range reaching the film to such an extent that the increased sensitivity of the film is counterbalanced by absorption in the filter. Thus the effective sensitivity of the film under the filter is uniform over this energy range, as is shown by the lowest curve in Figure 4. By this means doses of radiation with an energy greater than 90 keV can be directly estimated by comparing the blackening under the tin filter with a curve drawn of the dose-density relationship for, say, radium gamma radiation.

At lower energies a correction factor must be derived from a comparison of the apparent doses under the tin and duralumin filters. (Figure 4, middle curve.) Below about 60 keV the correction factors become too large to be practical and doses are estimated by comparison with standard films exposed to 30 keV radiation. In this case correction factors can be obtained from a comparison of the apparent doses on the duralumin and unscreened portions of the film. In practice, if an error of ±10% is permitted it is found that only a very small proportion of films require the application of correction factors.

This holder was specifically designed for use with the personnel monitoring films manufactured by Ilford Ltd.—PM1 films in the range 60 keV upwards and PM3 film at lower energies. Other emulsions would require slightly different filters but the principle would remain the same.

(For the sake of uniformity all energies have been referred to in keV which should not, of course, be equated with the kilo voltage applied to an X-ray tube. For example, radiation produced from an X-ray tube operating at 150 kV has an effective energy of about 60 keV.)

Interpretation of the film

The holder permits the estimation of dose over a wide range of energies and also produces a pattern on the film which gives a clear indication of the radiation source responsible for the dose.

The response of the film to beta radiation is similar to that for gammas but the presence of a beta dose is clearly indicated by the contrast between the plastic shielded area and the open window. Since the combination of beta-ray hazard and X-rays is a very uncommon one, it is usually safe to take the beta dose as the difference between the apparent doses recorded in the open window and the duralium shielded areas. With experience, a considerable amount of information can be derived from the appearance of a monitoring film; some examples are shown in Figure 6.

An incidental property of the film is its sensitivity to radiation emitted by free active material settling upon it (Figure 6D). This appearance, which is easily recognizable, is taken to indicate the presence of radioactive contamination of the working atmosphere. In some contexts, such as radium luminizing, this implies bad working conditions, while elsewhere it may show that a sealed source has become damaged and is leaking.

The need for two types of monitoring film is brought about by the wide variation in response of the emulsion to different radiation energies. The fast emulsion needed to achieve a satisfactory response to gamma radiation is saturated by a dose of about 800 mr of 100 kV X-radiation. This difficulty can be got over by using a film with different emulsions on the two sides of the film base: a fast emulsion to give sensitivity to high energy radiation, which can be stripped off if it is saturated, and a slow emulsion with a much greater range. A suitable combination has been produced for the Kodak 'Radiation Monitoring' film. There is not, at present, a satisfactory filter system in commercial production for use with this film, although one has been designed (*4*).

Keeping long-term records

In the past, although dosage records would have been of value when it came to following up cases of radiation injury, little attention was given to them since the recommended maximum permissible levels were expressed in terms of a short period. However, the new concept of setting long term maxima which are lower than summed short-term permitted doses introduces a need to maintain cumulative records and individual dose histories. Workers move from job to job and it is clear that a radiation records scheme will have to be created to deal with this problem.

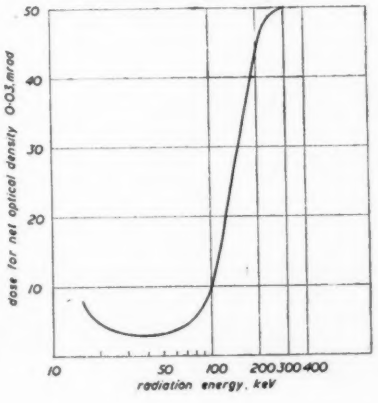
Another problem which arises in any dosage recording system is that of the threshold dose to be recorded. A corollary of the energy dependence of the emulsion is a similar wide variation in the threshold of measurement. Since the threshold at high energy is a significant fraction of the average permitted weekly exposure, the best procedure when accumulating data for radiation histories would be to use the threshold relevant to the energy of the exposure where this is known. This variation in threshold is demonstrated in Figure 7. From the point of view of measurement threshold a longer test period is advantageous because the probability that a measured dose will be recorded is improved and the threshold in any case represents a smaller fraction of the permitted dose.

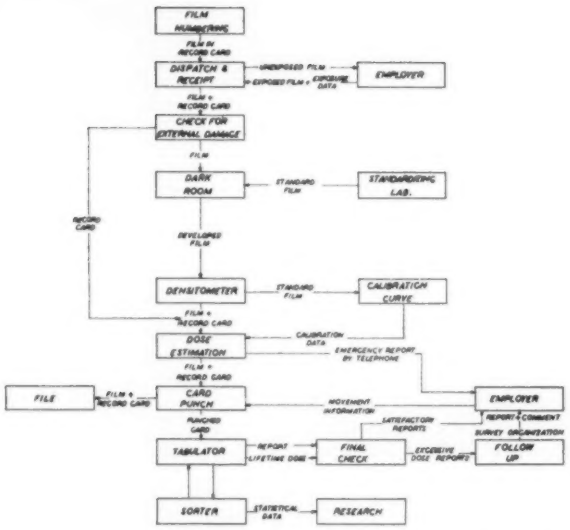
For the past eighteen months all doses recorded by films issued by the Radiological Protection Service monitoring service have been transferred to punched cards. Valuable experience has been gained, experience which has greatly helped in the design of a scheme meeting the requirements of the latest ICRP recommendations.

How the service is organized

The organization of the R.P.S. monitoring service (Figure 8) does not

Variation of dose measurement threshold with energy (Fig. 7)





Operation of the R.P.S. monitoring service shows the organizational, technical and instrumental needs of such a service (Fig. 8)

represent the only way of operating, but it does serve to illustrate the organizational, technical and instrumental needs of such a service. Currently, the bulk of the work, which amounts to rather more than 3000 films per week, is done for workers who are continuously monitored. Films, serially numbered by pressure marking, are sent out in record cards (Figure 9) on which the exposure details are entered. The employer issues the films to his workers who wear them (generally for a two week test period) in the holders described above. At the end of the test period, by which time a fresh supply of films will have arrived, the films are collected up, the record cards are completed and both items returned to the RPS laboratories at Sutton.

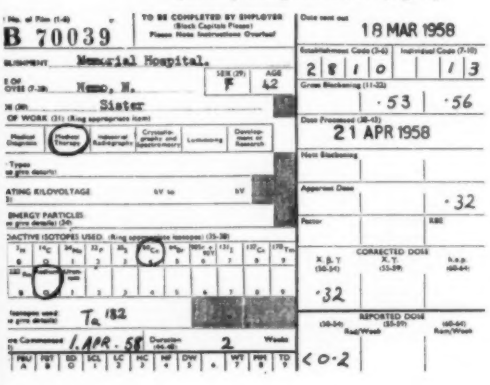
After they have been booked in, the films are given a visual examination for external damage and then developed in the dark room along with films of the same emulsion production batch which have been exposed to known doses of radiation—80 kV X-rays in the case of PM3 film and radium gamma radiation for PM1 films. Development is carried out using 1D 42 for 3½ minutes in frames holding 144 films each.

After drying, the optical density of the films is measured using a densitometer and calibration curves relating dose and optical density are drawn from the standard films. In general only one density measurement need be taken on each monitoring film but for films which may require the application of a correction factor to the estimated dose two or more density measurements are made. The criteria for deciding when more than one measurement need be taken or, if taken, need be recorded, are derived from the performance of the holder (*3*). From the calibration curve the dose on each film is estimated and then a 'reported dose' is given in which the dose is rounded off upwards. If at this stage a film with a high dose is seen (dose >3 rad) it is reported by telephone to the employer.

The record card is now complete and the information is ready for transfer to a punched card. In effect a card is punched for each film. It shows the name of the worker and other details of the test together with code numbers which permit the worker to be identified by machine and to facilitate mechanical sorting when long term dose records are required. From these cards reports are printed showing the test details and the 'reported dose' in the test. Modifications are now under way to permit the production of reports which would show the worker's radiation status at the end of each test.

Reports showing a dose in excess of 300 mrad/week (or some other unsatisfactory feature such as contamination) are accompanied by a letter indicating the probable cause of the exposure and suggesting methods of preventing a recurrence. Where the test reveals conditions which the employer is unable to set right, a survey is made on site by a physicist who makes recommendations for improvement. In the past three year 80 such surveys have been made at factories for this and other reasons.

Records of exposure details are kept on specially designed cards (Fig. 9)



Monitoring fast and slow neutrons

The film thus provides a means of monitoring beta-, gamma- and X-ray dosage, it gives an indication of the dose and may provide a warning of the presence of free radioactive material.

In addition the film can be made sensitive to thermal neutrons by replacing part of the tin filter by a similar thickness of cadmium. Under slow neutron bombardment an (n, γ) reaction takes place in the cadmium resulting in a blackening on the part of the film shielded by the cadmium. Apart from this property, cadmium is very similar to tin as a radiation absorber so that a film holder intended for slow neutron measurement is indistinguishable from a normal one from the point of view of gamma and X-ray sensitivity.

The normal photographic emulsion is insensitive to fast neutrons and other high energy particles. Special emulsions are used, for fast neutron monitoring, in which the knock-on proton produced when a neutron is absorbed in hydrogenous material produces a developable track across the emulsion. The number of tracks is counted over a given area of the emulsion using a microscope and then the dose is estimated. Details of the method have been published elsewhere (*5*).

Throughout this article the needs of radiation workers only have been considered. Workers not directly involved in radiation work should not, in general, receive doses exceeding one tenth of the levels permitted to bona fide radiation workers. Shielding and administrative control measures can ensure that these lower levels are achieved, thereby reducing the numbers requiring personnel monitoring. Occasional tests for such workers would show whether conditions were remaining satisfactory.

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3. Dealler, J. F. B., Jones, B. E. and Smith, E. E. *Occupational Safety and Health*, 1958, *8* (3). July-Sept, ILO Geneva
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Reactors

First results on Zenith investigation

SOME details of the investigation into the reactor physics of the uranium 235-thorium-graphite system have been published by the AEA in the first unclassified report to come out of Winfrith (AEEW M4 'An interim report on the Zenith exponential experiments' by R. M. Absalom, I. R. Cameron, G. H. Kinchin, J. E. Sanders and D. J. Wilson). There has been no previous work on this type of system in the UK and a practical result of the measurements will be a revision of the estimated loading for Zenith. As described in the report, the exponential assembly is constructed from 6 ft long Zenith fuel elements excluding the top and bottom reflectors, mounted on a graphite pedestal, 4 ft 6 in. square and 2 ft 4¼ in. thick, which is seated on a ⅜ in. mild steel bed-plate. This is surrounded by one foot thick concrete shielding to a height of 2 ft 6 in. The fuel elements are located vertically on the graphite pedestal in a hexagonal array of 3 in. pitch, graphite spigots on the ends of the elements fitting into holes in the top of the pedestal. The upper ends of the fuel elements are held in an aluminium grid plate which is supported by four posts at the corners. The system is excited by means of four half-curie Ra/Be sources placed in two horizontal channels through the shielding and the mid-plane of the graphite pedestal intersecting at the vertical axis of the system. The sources are positioned at a distance of 27·6 cm from the axis corresponding to the 3rd harmonic mode. When not in use the sources can be withdrawn into coffins permanently positioned on the four sides of the pedestal, outside the concrete shield. The strength of each source is about 6×10^6 n/sec. The pellet patterns corresponding to the various assemblies to be studied are shown in Fig. 2. They are based on a constant thorium pellet spacing of 1·539 in. (nominal).

TITLE	PELLET RATIO U:Th	S	N	S/N	PELLET SPACING (cm) U	Th	NOTES
5106	3:4	5124	12·66	404	3·25	3·94	
3830(1)	1:1	3843	9·51	404	3·94	3·94	
3830(2)	1:1	3843	9·51	404	3·94	7·88	*Th pellets paired*
3830(3)	1:1	3843	9·51	404	7·88	3·94	*U pellets paired*
2872	4:3	2882	7·15	403	2·955	3·94	
2393	8:5	2402	5·97	402	2·46	3·94	

Fig. 1 Systems investigated. S = Carbon atoms/U235 atoms. N = Thorium atoms/U235 atoms. S/N = Carbon atoms/Thorium atoms

The slight decrease of S/N as S decreases is due to the replacement of graphite pellets by uranium pellets. The pellet spacings have been derived from measurements of the overall lengths of the pellet array: the thorium spacing of 3·94 cm (1·552 in.) is 0·8% greater than the value of 3·91 cm (1·539 in.) obtained by summing the nominal pellet thickness. Main figures of the systems were:—

Graphite sleeves, inside diameter	2·87 cm
,, ,, outside diameter	7·37 cm
Triangular array of sleeves, pitch	7·62 cm
Total number of sleeves	235
'Effective radius' of stack approx.	61·3 cm
Voidage	15·2%
UO_2 pellets, diameter	2·84 cm
,, ,, thickness	0·173 cm
,, ,, U-235 content	1·405 g
ThO_2 pellets, diameter	2·83 cm
,, ,, thickness	0·261 cm
,, ,, thorium content	13·2 g

Basic quantities to be determined were the vertical relaxation distance of the flux and the extrapolated radius of the system. The team state in their report that the extrapolated radii deduced from the measurements do not show any obvious correlation with direction of measurement, height of the measurement plane or composition of the system. 'From the data obtained so far, an extrapolated radius of 63·5 ± 0·3 cm has been derived as a mean. The geometrical radius of the system, using an area equivalent to convert to a cylinder, is approximately 61·3 cm (the 'edge' of the fuel element array is a rather vague

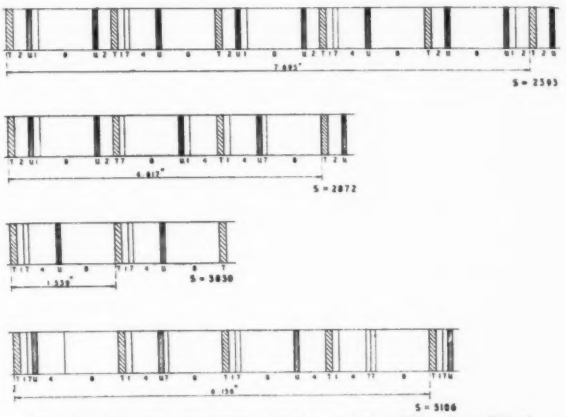

Fig. 2 Loading patterns. Code: U = U235, T = Thoria, 7, 1, 2, 4, 8 = 0·068, 0·100, 0·200, 0·400, 0·800 in. graphite

quantity). An extrapolation distance of 2·2 cm is thus implied, which agrees well with the calculated value of $0{\cdot}71\,l_t$'. Relaxation length measurements with indium foils agreed within their relatively large statistical error, with values derived from BF_3 counter scans.

The data has been analysed on a two-group model (multigroup analyses are in progress), and factors which have been included in deriving the parameters needed in the analysis include:

- **a.** Variation of effective neutron temperature with composition of the system.
- **b.** Self-screening in the U-235 pellets, which has a considerable effect on the thermal utilization and diffusion length values.
- **c.** Streaming along the gaps between the fuel elements; the resultant anisotropy in the diffusion and slowing down areas is derived using Behren's formulæ.

'For the first two systems (5108 and 3830/1) values of p found from the two group analysis are not inconsistent with the value of 0·93 from the Monte Carlo calculations of Morton, Bannister, and Brinkworth', says the report. 'The cadmium ratio measurements on the indium foils can be compared with calculated values derived from the nuclear parameters of the systems and the effective resonance integral of the foils obtained from the measurements in Gleep. The calculated values for systems 5106 and 3830/1 are 2·62 and 2·29 respectively, to be compared with the measured 2·45 ± ·05 and 2·27 ± ·04.'

Instrumentation

Microwave diagnostics in plasma research

by S. M. HAMBERGER, B.Sc., A.Inst.P.
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THE use of microwaves for studying plasma properties in thermonuclear experiments is a logical development of ionisphere sounding by radio waves; the difference in technique used lies in the much higher density, temperature and magnetic field in the plasma. Considering, for simplicity, only propagation of frequencies above the plasma frequency $f_p \simeq 9{\cdot}10^3 n^{\frac{1}{2}}$ (where n is the electron density per cm^3), provided that the wave electric vector is parallel to the magnetic field B, or in any case if the electron cyclotron frequency f_c (equal to 2·8 Mc/s per gauss) is small compared with f_p, the propagation does not depend on B or temperature, and the dispersion equation may be written as

$$\gamma = \alpha + j\beta = j\frac{\omega}{c}\sqrt{\left(1 - \frac{\omega_p^2}{\omega^2 + \nu^2} - j\frac{\omega_p^2}{\omega^2 + \nu^2}\,\frac{\nu}{\omega}\right)} \quad (1)$$

where $\gamma = \alpha + j\beta$ is the propagation constant, $\omega_p = 2\pi f_p$, ν = electron collision frequency. If we can measure the attenuation constant α and phase constant β in the plasma we can then solve equation (1) to find n and ν. Ignoring collisions the dispersion equation may be simplified to to $\mu^2 = 1 - \omega_p^2/\omega^2$ . . (. 2) where μ is the refractive index in the medium at angular frequency ω. When $\omega > \omega_p$, μ is real and <1, and the wave propagates. When $\omega < \omega_p$, μ is imaginary and the wave is totally reflected from the

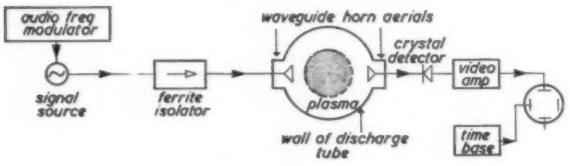


Fig. 1 Density measurement

plasma. Thus if we measure the critical frequency at which 'cut-off' occurs we have a simple method of finding n. Since thermonuclear plasma usually have densities in the range 10^{13}–10^{16} cm^{-3}, the corresponding free-space wavelengths for cut-off are in the range 8 mm to 0·3 mm, i.e. in the short microwave to far infra-red region.

Measurement of Electron Temperature

It is well known that if a transmission line is terminated in a matched impedance which is at an absolute temperature T°K then a matched receiver of band width B would receive a noise power equal to kTB, where k is Boltzmann's constant. If the termination is a gaseous plasma, then, provided that it presents a matched impedance to the line the noise power received is kT_eB where T_e is the electron temperature in °K. Suppose now that we present a waveguide aerial to the plasma in such a way that *at certain frequencies* a signal transmitted to the plasma is completely absorbed by it, then we may deduce that the noise power reaching a matched receiver at the other end is a measure of the electron temperature of the plasma.

Since frequencies below f_p are not absorbed but are reflected by the plasma no noise will reach the receiver in this band. Frequencies above f_p are transmitted, the amount of absorption depending on the number of electronic collisions along the waves path, i.e. nν. If the plasma is not very dense, or the temperature is very high (ν small), or the path length in the plasma too short, then complete absorption does not take place and the plasma is said to be 'optically thin.' In such circumstances the power radiated is less than the black body value of kT_eB. Dellis (*1*) has considered this in some detail and has concluded that in fact over a narrow band around the plasma frequency

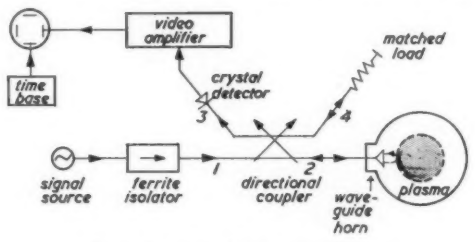


Fig. 2 Plasma velocity measurement

f_p the radiation does reach the black body value. Since in any plasma produced in practice the density is not uniform there is in fact a range of frequencies over which black body radiation is observed; it must be realized that this radiation can come only from those regions of the plasma to which an inwardly directed wave at the same frequency can penetrate. Hence observing the noise radiated at different frequencies can tell us something of the temperature in different parts of a plasma.

As previously stated the wavelengths required for transmission through the plasma lie in the range 8 to 0·3 mm. Fusion reactors will probably work at higher densities, necessitating even shorter wavelengths. Two things result: firstly the physically small size of the waveguide equipment required, e.g. aerial horns, etc. will be an advantage since high gain aerials may be used to inject well defined beams into a comparatively large plasma (dimensions of the order of 10–100 cm), and the waves will approximate to TEM waves in an infinite plasma. Secondly, except at the long wavelength (Q band) end of the range mentioned there are few readily available microwave components. A recent review by Kaufman (*2*) usefully summarizes the present state of the submillimetre art, and contains a full list of references.

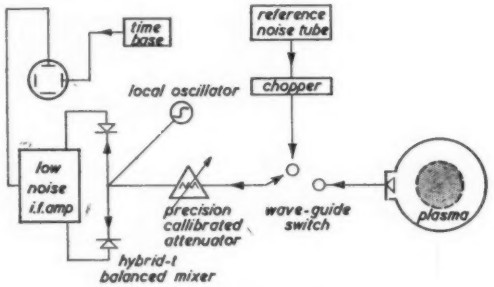


Fig. 3 Temperature measurement

Methods Used (*3*)

1. Transmission This is the simplest measurement and shows when the plasma density passes through a value at which its critical frequency f_p equals the signal frequency. The microwave signal is modulated at audio frequency and the variation in the detected amplitude displayed as a function of discharge time on an oscilloscope (Fig. 1). A similar method can be used to investigate the density of the space outside the pinched discharge in pinch machines such as Zeta. In this case a frequency which will not normally propagate is used: the signal is passed when the plasma pinches so that the density in the 'vacuum' is sufficiently reduced, thus giving information about the time at which the pinch forms.

2. Reflection A directional coupler (Fig 2) is used as a reflectometer to measure the signal reflected from the plasma. This is small until the plasma density rises above the critical value, when it increases sharply. If the discharge is such that a well defined current sheath is formed then the rate at which this moves radially inwards can be found by an interference method: a discontinuity is introduced in arm 4 of the directional coupler from which a signal is reflected into arm 3 with a fixed phase. The signal reflected into arm 3 from the moving plasma will have a rapidly varying phase, the detected output of arm 3 will show maxima and minima when plotted against time. The time between successive maxima corresponds to the plasma moving a half wavelength, whence the plasma velocity can be determined.

3. Radiation The noise radiation is fed to a low noise superheterodyne receiver via a horn aerial and waveguide precision attenuator (Fig. 3). Noise level is compared by means of the attenuator with that of a standard noise source fed to the same receiver. Knowing the electron temperature of the standard source that of the plasma can be readily deduced. If for example, T_e for the noise source is known to be 10,000°K, and the plasma noise is measured as 17 dB (corrected for wave guide loss) above that of the noise source, then the electron temperature of the plasma is $10{,}000° \times \text{antilog}_{10} \frac{17}{10} = 500{,}000°\text{K}$. The comparison of noise pulses from the plasma with the reference source is made easier by modulating the latter, e.g. by a rotating attenuator or ferrite switch.

References :

1. Dellis, A. N., *AERE GP/R2265 (1958)*
2. Kaufman, J., Proc. I.R.E., Vol. 47, No. 3 (March, 1959)
3. Harding, G. N., *et al, 2nd Conference on the Peaceful Uses of Atomic Energy*, Geneva, 1958, P/1520
4. Dolgov-Saveliev, G. G., *et al, ibid*, P/527
   See also C. B. Wharton, *et al*, Geneva Conference (1958) P/381

Processes

A concentrator for radioactive wastes

AN EVAPORATOR which might offer a new approach to the problem of large scale concentration of highly active separation plant raffinate is described in AEA report IGO-R/W-70 'A remote controlled shielded evaporator for laboratory use' by A. J. Howarth of the Operations Branch, Windscale. In its present small scale form the unit will operate continuously, removing up to 20 litres/day of water, with some nitric and hydrochloric acids, from active analytical waste liquor at a cost of about 6d/litre; it can be put together, operated, and taken apart remotely. The report includes a sectional view (Fig. 1) and describes the principles of operation as follows:

160 litres/min. of cold air at a pressure dependent on pressure drops in the apparatus, and supplied with about 900 W, passes through a heater. This air, at about 350°C, passes down a tube C to the bottom of the packed column D where it meets hot liquor. Water is taken up, and the air passes up through packing, first becoming saturated and cooling to about 95°C, then passing a dry section where entrained spray is taken out. A little heat is absorbed here from the hot air inlet tube, and the air leaves the column at 97–99°C to enter the scrubber E, of similar proportions to those of the evaporator. Here it meets cold water in counter-flow, and leaves by the exit pipe F for the cubicle exhaust. Raw feed is admitted to the evaporator by a dip-line in the tube B and after removal of water it falls to the bottom and flows into the product tank, where it may build up and re-enter the evaporator at the tube B for a second stage of evaporation. It is eventually drawn into the product meter H. Here it is recycled and mixed with product in the measuring vessel G by means of the airlift J and the overflow K. It is removed from the vessel batchwise at will by placing a flat-based plug over the air vent P.

Cold water at about 20 litres/h is allowed to fall into the tundish L and enters the scrubber by the lute M, leaving at the bottom after taking heat, moisture and volatiles from the wet air stream. The bulk of this water passes through the outer tank into which it is discharged, and over the exit weir N, which is an overall level control. Make-up for raw feed flow-rates below maximum is taken automatically from the outer tank by the tube A.

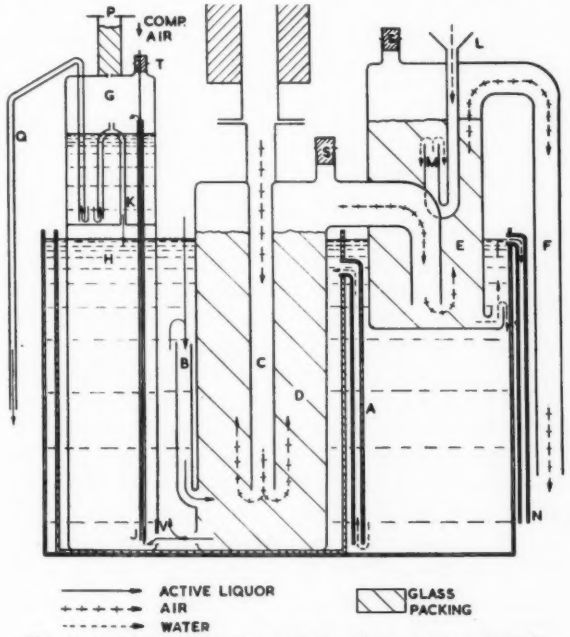


Fig. 1 A bottom-feed ring-packed column with automatic recycling is employed

an adequate barrier to loss of solids being the layering due to density in the inner (product) tank, and to a lesser degree in the outer (water) tank. A separate unit similar in design is used to remove chloride from the concentrate.

Modern spectroscopes are now widely used for both basic nuclear research and swift routine analysis

Mass Spectroscopy as a research tool

by A. H. TURNBULL, B.Sc.

Mass Spectrometry Group, A.E.R.E., Harwell

IN the years since 1919, when F. W. Aston built his first mass spectrograph, the instrument has found application as a research tool in many branches of science—physics, chemistry, geology, biology, medicine. Simultaneously, thanks to improvements in design detail and to what is known across the Atlantic as 'ruggedization,' modern commercially-available instruments are capable of swift and accurate routine analyses in semi-skilled hands.

The majority of commercially-available spectroscopes are basically of the same pattern; the principles of operation are shown in Figure 1. Positive ions are produced in an ion source at S and are accelerated by a high voltage through a number of focusing and collimating slits to enter a homogeneous sector-shaped magnetic field. Under the influence of this field, ions of a particular mass-to-charge ratio travel along one circular arc while those of another mass-to-charge ratio follow a different arc. In this way the ions are sorted out according to their masses, if we consider only singly-charged ions, i.e. atoms which have lost one of their outer electrons.

By suitable adjustment of the magnetic field strength or of the ion-accelerating voltage (usually the former), the ions of a particular mass pass through the exit slit and are collected on a plate whence they leak to earth through a high-value resistor. The voltage developed across this resistor is suitably amplified and provides a measure of the intensity of the ion beam. If the ion current is measured by an electrical method such as the above or by an electron multiplier or particle counter, the instrument is called a mass spectrometer. If the final slit is absent and the resolved ion beams fall on a photographic plate producing a series of line images, the instrument is known as a mass spectograph. The term mass spectroscope covers both types.

If the substance to be examined by the mass spectroscope is a gas or a liquid with a vapour pressure of the order of 1 mm of mercury at room temperature, the gas or vapour molecules are simply allowed to flow into the instrument where they are subjected to bombardment by electrons emitted from a hot filament. Electrons are thus removed from the molecules, leaving positive ions. If the substance to be analysed is a solid, it can be vaporized by heating in a small furnace; the vapour molecules issue from a slit in the lid of the furnace and are ionized by electron bombardment as before.

Where possible, however, positive ions are produced from solid materials by means of the surface ionization type of ion source. Here, a solution or slurry of the material or one of its compounds is placed on a filament which is electrically heated. The material evaporates from this filament, some as positive ions and some as neutral molecules. The ratio of positive ions to neutrals depends on the difference between the work function W of the filament surface and the ionization potential ω of the material being ionized. When $(W-\omega)$ is positive the process is relatively efficient. If it is negative, the efficiency of ionization is low but can be increased by raising the temperature of the filament. This may result in the sample material being evaporated so rapidly, however, that insufficient time is available in which to make an analysis. This difficulty is overcome by using a triple-filament ion source (Figure 2). The sample under investigation is placed on one or both of the filaments F_1 from which it is evaporated at a rate controlled by means of the heating current passed through F_1. Some of the evaporated atoms or molecules impinge on the centre filament F_2 where they are ionized by the surface ionization process. For a given $(W-\omega)$ value, the efficiency of ionization is controlled by the temperature of F_2 which can be varied independently of that of F_1.

One of the main advantages of the surface ionization type of source is that it enables very small quantities of material (10^{-6} to 10^{-10}g, depending on the ionization potential of the substance) to be analysed.

Thus the function of a mass spectroscope is divided into three parts: 1. the production of ions, 2. the separation of these ions according to their masses, and 3. the measurement of the relative intensities of the different

ionic species. These processes take place within a highly evacuated chamber, since otherwise the positive ion beam would be rapidly scattered by collisions with extraneous gas molecules. A commercial gas-source mass spectrometer with its attendant power supplies and control circuits is shown in Figure 3. The mass spectrometer tube is inside the cubicle on the right of the photograph. The gas-handling system is mounted on the front of the cubicle.

PHYSICAL AND CHEMICAL APPLICATIONS

a. Determination of atomic masses

The observed mass of an atom is always less than the sum of the masses of its constituent protons, neutrons and electrons. This mass defect represents the binding energy of the nucleus and is a measure of the nuclear stability. Thus an accurate knowledge of atomic masses enables the physicist to predict nuclear reactions and nuclear decay transitions.

The mass spectroscope is used to compare atomic masses by the study of 'doublets.' A doublet is a pair of mass-spectral lines produced by two sorts of ion whose mass-to-charge ratios are only slightly different. So far we have considered only singly-charged ions in the mass spectroscope and have said that the instrument sorts out ions according to their masses. It was pointed out earlier, however, that the path which an ion follows in the mass spectroscope is determined by its mass-to-charge ratio. Thus a doubly-charged ion of an atom of mass M_1, i.e. an atom which has been stripped of two electrons, has a mass-to-charge ratio of $M_1/2e$ and will follow almost the same path in the mass spectroscope as a singly-charged ion of mass-to-charge ratio M_2/e if $2M_1$ and M_2 are only slightly different. If M_1 is known, M_2 can be calculated from a measurement of the doublet spacing and a knowledge of the dispersion of the mass spectroscope. This doublet technique is used because of the relative ease of obtaining uniform dispersion over the small separation of the doublet members.

Until the early 1950's, most atomic masses were determined with mass spectrographs in which the lines of the doublet were recorded simultaneously on a photographic plate. More recently, electrical recording methods have been used which enable a linear dispersion to be achieved over a much wider range than in the mass spectrograph.

b. Half-life determination

The half-life of a radioactive species is another quantity which is of fundamental importance to the nuclear physicist and engineer. The equation governing the decay of a radioactive isotope is

$$N/N_0 = \exp(-\lambda t) = \exp(-0{\cdot}6932t/t_{\frac{1}{2}})$$

where N = number of atoms of the isotope at time t
N_0 = number at zero time
λ = decay constant and
$t_{\frac{1}{2}}$ = half-life.

In principle, therefore, by measuring N_0 at zero time and N at time t, the half-life $t_{\frac{1}{2}}$ can be calculated. In practice, the adundance of the radioactive isotope is periodically measured relative to the stable isotopes of the element.

If the half-life is long, greater accuracy can be achieved by measuring the rate at which the daughter is formed by disintegration of the parent isotope, since in this case even a small number of disintegrations will cause a relatively large change in the abundance of the daughter.

c. Isotope dilution analysis

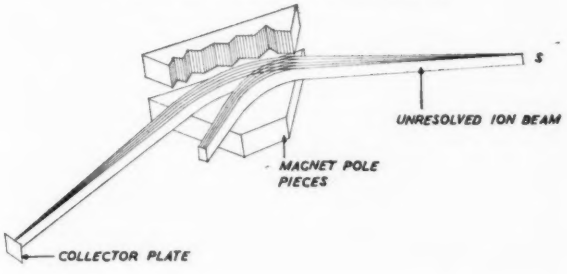
Isotope dilution analysis provides a means of determining the quantity of a particular element or isotope of that element in a sample of material. Suppose that we are interested in the determination of an element which is in its natural form in the sample material; being natural, its isotopic composition is known. To a weighed amount of sample material is added a weighed amount

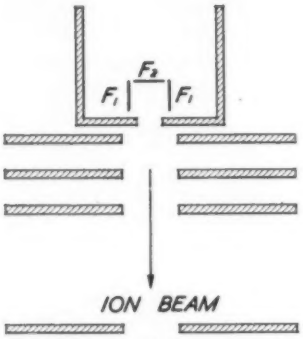
TYPICAL APPLICATIONS

- measurement of atomic masses
- isotope dilution analysis
- half-life determination
- neutron absorption cross-sections
- fission yields
- branching ratios
- high temperature studies
- leak detection
- free radical studies
- geological age determination

of a tracer or spike, which is a form (usually stable) of the element having an isotopic composition different from that of the element in the sample. The tracer is usually prepared by electromagnetic separation and its isotopic composition is determined by mass spectrometer. In the mixture of sample and tracer, the isotopic composition of the element is, of course, different from that in either of its components considered separately. The element is extracted chemically from the mixture (although this step is sometimes unnecessary) and the modified isotope ratio is determined mass spectrometrically. Knowing the isotopic compositions of the sample, the tracer and the mixture, and the weight of tracer element used, it is possible to calculate the amount of

In a sector-type mass spectrometer ions from a source S are accelerated by a high voltage through arcs whose radii depend on the mass of the ions (Fig. 1)





By using a triple filament ion source the efficiency of evaporation can be more easily controlled (Fig. 2)

the element present in the original sample.

The method is applicable to any naturally poly-isotopic element and can even be used to analyse for a mono-isotopic element if there exists a long-lived radioactive isotope suitable for use as a tracer. It has been used to measure the amount of uranium-235 in spent reactor fuel elements, thus determining the extent of burnup.

d. Neutron absorption cross-sections

These cross-sections can be determined by a process which involves isotope abundance measurements by mass spectroscopy. If a sample of some material is subjected to neutron irradiation in a nuclear reactor, the rate of absorption of neutrons by a particular isotope is given by

$$dN/dt = -\sigma NF$$

where N = number of atoms of the isotope
σ = the neutron absorption cross-section of the isotope
F = the neutron flux.

Thus after a time of irradiation t, the original number of atoms N_0 of the isotope will have fallen to N, where $N/N_0 = \exp(-\sigma Ft)$. With a knowledge of F and t, the neutron absorption cross-section of the isotope can be calculated by measuring with a mass spectrometer the change in the relative abundance of the isotope

In this typical gas source instrument the spectrometer tube is in the cubicle on the right with the power supplies and control panel on the left (Fig. 3)

e. Fission yields

The masses of the products of slow neutron fission of uranium-235 may lie anywhere between fairly wide limits. If the measured yield of a fission product of a certain mass number, expressed as a percentage of a number of fissions, is plotted against mass number, a double-humped curve is obtained extending from mass 80 to mass 154 (Figure 4). Superimposed on each hump is a fine structure peak—one at mass 95 and one at mass 140. These peaks, which were discovered in the course of mass spectrometric investigations of fission yields, were unexpected theoretically at that time. It is now believed that the divergence between theory and observation can be attributed to the highly stable nature of fission fragments with a closed shell neutron configuration (50 or 82 neutrons). Further mass spectrometric study of fission yields is aimed at elucidating this point.

f. Branching ratios

Zinc-64 is an even-even stable nuclear species, i.e. its nucleus contains an even number of protons ($Z = 30$) and an even number of neutrons ($N = 34$). Nickel-64 is isobaric with zinc-64 (i.e. they both have the same mass number) but its nucleus contains two more protons and two less neutrons. There are, in fact, among the known stable nuclides, 62 stable even-even isobaric pairs, such as the above, with atomic numbers differing by two. Between the members of each pair there lies an odd-odd nuclide of intermediate atomic number which, according to theory, is unstable and will decay either in the mode $Z \rightarrow Z + 1$, in which case a negative β-particle is emitted from the nucleus, or in the mode $Z \rightarrow Z - 1$ due to emission of a positive β-particle or to K-capture, i.e. the capture of one of the orbital electrons from the innermost quantum level, or K-shell. Generally, one of these two modes of decay will predominate; in a number of cases, however, branching has been observed, i.e. both modes of decay take place.

Valuable information concerning nuclear instability is provided by measurement of the branching ratio, i.e. the relative abundance of the products of the two modes of decay. The determination is made as follows: gram quantities of the element under investigation are neutron-activated in a reactor in order to produce an appreciable quantity of the unstable Z nucleus which is of interest. This is then allowed to cool for a period which is long compared with its half-life. The relative amounts of the $(Z + 1)$ and $(Z - 1)$ daughter products are determined by mass spectrometer, using the isotope dilution technique. The mass spectrometer does not, of course, distinguish between β^+ emission and K-capture in the $Z \rightarrow Z - 1$ mode of decay. However, considering the mass spectrometry results in conjunction with a determination of the β^+ emission by counting methods,

the percentage of the $(Z-1)$ daughter produced by K-capture can be determined.

g. High temperature studies

Over the past six years, a considerable amount of effort has been devoted to mass spectrometric studies of the gaseous species in thermodynamic equilibrium with various elements, oxides and metal-metal oxide systems, and to the measurement of latent heats of vaporization and sublimation. The substances to be examined are vaporized in a Knudsen cell, i.e. a small oven which is entirely closed save for an aperture of known dimensions. The vapour molecules effusing from the cell pass into the ion source of a mass spectrometer where they are ionized by electron bombardment in the usual way. The vaporizing species are identified and their relative abundances measured by the mass spectrometer.

By observing the dependence on cell temperature of the ion current due to a particular species, the latent heat of vaporization or sublimation can be derived from the Clausius-Clapeyron equation. Furthermore, by controlling the energy of the bombarding electrons, the appearance potentials of the various species can be determined. Systems studied in this way include the Group IV elements Ge, Sn, Pb, the systems Al-Al_2O_3, Si-SiO, B-B_2O_3, the oxides BaO, SrO, MgO and LaO and various alkali halides.

h. Leak detection

The mass spectrometer-helium probe method of detecting leaks in vacuum systems is probably too well-known to require explanation here. The technique is also of value, however, for detecting leaks in reactor fuel element cans which contain helium. In this case the mass spectrometer communicates with an enclosure surrounding the fuel can and responds to any helium leaking out of the latter into the former.

i. Free radical studies

Free radicals have been widely studied by mass spectrometry. The vapour to be studied is led into a reaction vessel where it is decomposed on a hot surface. The reaction products issue from an orifice in the reaction vessel to enter the ionization chamber of a mass spectrometer ion source where they are subjected to electron bombardment. The mass spectrometer enables free radicals to be identified readily and the presence of short-lived intermediate reaction products can be easily detected. The concentrations of all reacting species are continuously measurable, giving valuable information concerning the mechanism of the reaction. Furthermore, the ionization potentials of the reaction products can be measured without serious difficulty.

GEOLOGICAL APPLICATIONS

Mass spectrometry finds an important geological application in the determination of the ages of minerals and rocks. The mineral to be examined must contain an appreciable amount of some radioactive isotope whose half-life is comparable with the duration of geological time, i.e. of the order of 10^9 years, and since being formed it should not have suffered any addition or escape of this nuclide or the daughter product of its decay. The reactions which have been most commonly used for the determination of geological age are as follows:

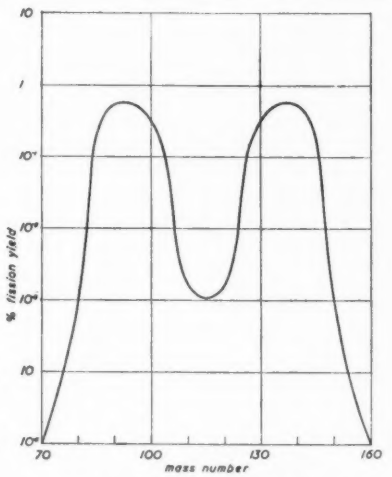
$$^{238}U \rightarrow {}^{206}Pb + 8\,{}^{4}He \quad (t_{\frac{1}{2}} = 4{\cdot}5 \times 10^9 \text{ years})$$
$$^{235}U \rightarrow {}^{207}Pb + 7\,{}^{4}He \quad (t_{\frac{1}{2}} = 0{\cdot}7 \times 10^9 \text{ years})$$
$$^{232}Th \rightarrow {}^{208}Pb + 6\,{}^{4}He \quad (t_{\frac{1}{2}} = 13{\cdot}8 \times 10^9 \text{ years})$$
$$^{40}K \rightarrow {}^{40}A \quad (t_{\frac{1}{2}} = 1{\cdot}3 \times 10^9 \text{ years})$$
$$^{87}Rb \rightarrow {}^{87}Sr \quad (t_{\frac{1}{2}} = 46 \times 10^9 \text{ years})$$

Of these reactions, the last two have been developed over the past three or four years until they are now probably the most useful of the dating methods.

In the rubidium-strontium case, the number of ^{87}Sr atoms formed in a time t is related to the number of ^{87}Rb atoms remaining by the equation

$$^{87}Sr/^{87}Rb = \exp(\lambda t) - 1$$

where λ is the decay constant. The ratio $^{87}Sr/^{87}Rb$ is measured by mass spectrometer.



The two well defined peaks of the fission yield curve for U-235 and slow neutrons were discovered by mass spectrometry (Fig 4)

^{40}K decays in two ways: by β-emission to ^{40}A, and by k-electron capture to ^{40}Ca. In this case the relevant equation is

$$\frac{^{40}A}{^{40}K} = \frac{\lambda_K}{\lambda_\beta + \lambda_K}\left\{\exp[(\lambda_\beta + \lambda_K)t] - 1\right\}$$

where λ_β and λ_K are the decay constants of ^{40}K for β-decay and K-capture respectively.

Methods of geological age determination have been developed to such a degree of reliability that discrepancies between the results obtained by different methods on minerals from the same region allow conclusions to be drawn concerning geological events in that region.

References :

1. Waldron, J. *Research* 1956, 9 p 306
2. Waldron, J. editor *Advances in Mass Spectrometry*. Proceedings of the Joint Conference on Mass Spectrometry, London, 1958. To be published by Pergamon Press

Cross Section by GRACCHUS

HAVING decided that it will have to do a lot more research and development on nuclear power stations itself instead of relying entirely on data supplied by the AEA, the Central Electricity Generating Board is determined to waste no time. Already a director has been appointed for the Berkeley laboratory —due to be completed by next autumn —and prospective staff are being interviewed. The present idea is to build up to a strength of about 500 and peg it there. Meanwhile R & D at Leatherhead is being stepped up: in addition to work on materials (including graphite), and heat transfer characteristics of fuel elements, a new group is to be formed to develop heat exchangers right up to the prototype stage. Incidentally a three-dimensional computer study of instability which was started in this country but later moved to the US (it was done on an IBM 704 there because of the non-availability of enough time on the British machine) is now almost complete.

I SUPPOSE the never-ending struggle between design, operating and safety people is inevitable and perhaps even extremely useful, but though arguments may get pretty abusive at the drawing board stage on such topics as whether to design for half a million pounds' worth of remote handling gear or let a man nip in for three minutes with a spanner the operator will doubtless continue to think up his own little tricks in the end.

One such, related in the Annual Report for 1958 of the Chief Inspector of Factories, just published, concerns an industrial radiographer (now partly bald). The doors of the X-ray rooms at his works are interlocked with the main switch, and a red light indicates when the current is on. The controls are outside. A good, safe system, one might think, but the designers didn't reckon sufficiently on the labour saving instinct. In practice our radiographer, and possibly others, worked out the following routine:

1. Before entering the room to remove work just photographed and place new work in position, adjust the settings on the switchboard outside for the new exposure and leave the main switch on,
2. go in and reset the work,
3. close the door and press the button on the time switch.

The exposure can thus be started without using the main switch, which is in effect replaced by the door. In addition more labour can be saved by not bothering with the plumb line to centre the tube, but placing the head close to the aperture and looking vertically downwards to ensure proper setting.

Unfortunately, one day while he was in the middle of it all, someone closed the door. This of course switched on the current. Two weeks later he attended the works surgery with a patch of baldness about 1½ in. in diameter on the top of his head. 'He escaped very lightly' says the report . . .

WILL trains of lorries carrying tenders for nuclear power stations soon become a familiar sight in the streets? According to Sir George Dowty the industry is rapidly submerging under mounting tons of paper. His statement to the Annual General Meeting of the Dowty Group contains the following *cri de coeur*: 'I am sorry to say that in general the young and enthusiastic nuclear industry is fast becoming a paper work industry of tenders and quotations.' He adds that the total national effort devoted to the preparation of tenders for 'this complex equipment' often approaches the total value of the contract. Though I feel he goes a little far, there is undoubtedly a lot of paper in the business. I calculate that tenders for the five stations so far ordered in the UK alone weighed more than 20 tons, and money spent in preparing tenders must now be well past the £1 million mark. And this is for home contracts only. The whole thing presents quite a dilemma but against this it must be remembered that the work involved will diminish as firms accumulate drawings and specifications in what after all is a very new field. And could it be suggested that some groups are not as efficient in preparing tenders as they might be? While one gives £250,000 as the cost of their first bid for a station, another maintains that they did the job for not much over £100,000.

I AM GLAD to hear that the government is coming round to the idea of a National Radioactive Waste Disposal Service for industry. This would be an advance on merely incorporating safety standards in the new factory regulations. The set of proposals for national rules on what firms can and cannot do with the stuff, which were drawn u after discussions in the last Parliamer are, I understand, still going th rounds. Certainly users would be gla to have the thing put on a nation basis instead of the present local coun cil set-up, which is obscure enough t send two or three companies a wee to Harwell pleading for guidance.

PUBLIC enquiries on siting of nuclea power stations, research establishment etc. can get fairly lively in this country, but I've seen nothing to match a shindig reported to me from the US recently. The Walker Trucking Co. of New Britain, Connecticut, wants authorization to package and store radioctive by-product and source material at an additional site. The AEC attitude is favourable but the company is opposed by the Mayor of New Britain and a group of some 1500 people who have signed a petition. The hearing was acrimonious and marked by statements of suspicion against both the AEC and the Government. The last straw came after a protest by the petitioners that they needed expert advice and time to get it. Someone was heard to refer to them as 'a bunch of ignorant people' and the whole thing almost broke up in disorder. The AEC litigation counsel protested in vain that no one in the AEC had made the statement. People in the audience shouted 'They did, they did' and a woman identified the individual as 'the man right there in the light grey suit.'

Man in grey suit: 'Me, I don't work for the AEC.'

AEC Litigation counsel: 'No he does not work for us.'

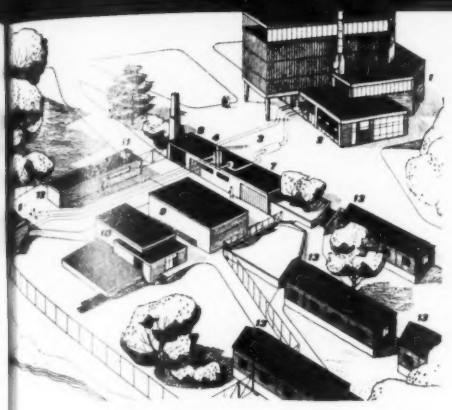
Afterwards the man declared he merely happened to be seated at the AEC table because there was a chair available. (Cries from the audience of 'who are you' etc.)

On Record

It is wrong that the heavy electrical and boilermaking industry after encouragement . . . to take considerable risks to meet the nuclear power programme . . . should now be in the position of such delayed profits—in fact in some cases, immediate losses.
Sir Edward Thompson.

I stood silent for a moment and then turned away. I had never seen her cry before. She had remained as controlled as an automatic reactor. Now, perhaps we'll get to the heart of the matter, I thought. . . .
Story in 'Woman' magazine

Zeta we find extremely difficult to understand.
Sir William Penney



COMPLETE FACILITIES. The overall reactor area comprises 1. Reactor building, 2. Control room, 3. Delay tank, 4. Primary pump house, 5. Secondary pump house, 6. Aldermaston Lake, 7. Water demineralization plant, 8. Boiler house, 9. Sub-critical laboratory, 10. Effluent treatment plant, 11. Change room, 12 Active storage area, and 13. Laboratories and office

MERLIN

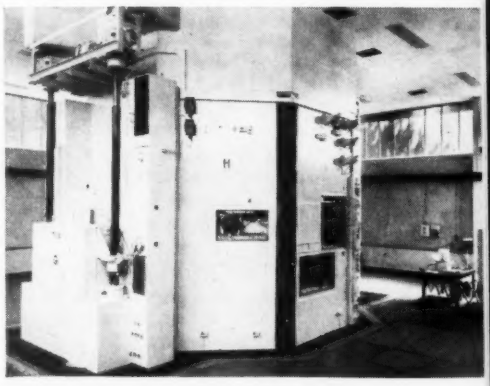
AEI's high flux reactor

THE FIRST privately owned reactor, Merlin, has been brought into operation. Built by AEI-John Thompson Industrial Nuclear Energy Group for AEI's research laboratory at Aldermaston Court in Berkshire, fuel loading commenced on July 7 and it became critical on July 16 (see *Worldview*, August).

This medium energy research light water-moderated reactor began as a design study in 1955 at the request of the United Kingdom Atomic Energy Authority. Originally the maximum power level was set at 1MW, but the reactor was subsequently redesigned so that it would operate continuously at 5 MW, as there appeared to be a demand from overseas for a higher powered unit and partly due to shortage of test facilities in the UK.

The complete installation was built at a cost of £575,000, of which £275,000 was absorbed by the cost of the reactor proper and £120,000 for the uranium fuel. When operating at full power and allowing for 100% depreciation or amortization over a period of ten years, the operating charges are anticipated to be approximately £100,000 per annum. These costs, when considered in relation to the maximum radiation fluxes and extensive experimental facilities available, compare very favourably with the operating costs of a 10MW reactor, such as Dido or Pluto, which range between £500,000 and £M1 a year.

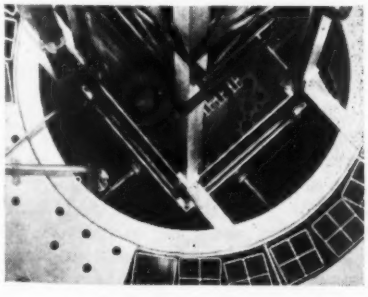
The Merlin reactor incorporates a core which can be moved vertically to give four stations. The top position permits easy manual withdrawal of fuel or experimental apparatus from the core and the lowest position is for storage purposes and is so arranged that it is virtually impossible for loss of coolant to occur. By having two intermediate positions, the maximum number of experimental facilities are incorporated. With the core in the lower operating position, two horizontal graphite thermal columns, 7 ft 4 in. long and 4 ft 6 in. square at the experimental face of the shield; one 12 in. and three 6 in. diameter horizontal beam tubes; and a vertical hole in the core, 24 in. × 3 in. × 3 in. are available. When the core is brought into the upper operating position, four 6 in. diameter horizontal beam tubes; two 6 in. diameter tubes straight through the reactor passing close to the core face; two 6 in. × 3 in. section vertical tubes parallel with and close to the core face; a vertical hole in the core, 24 in. × 3 in. × 3 in.; and a shelf to take objects, of maximum dimensions about 2 ft cube, up to the core face may be used. Remote controlled mechanisms have been used to operate the shielding of the thermal columns and sealing plates of the horizontal facilities—these latter function in a similar manner to the breech blocks of guns, in that after moving across the face of the tube they move a short distance inwards to form a gas and liquid tight seals.

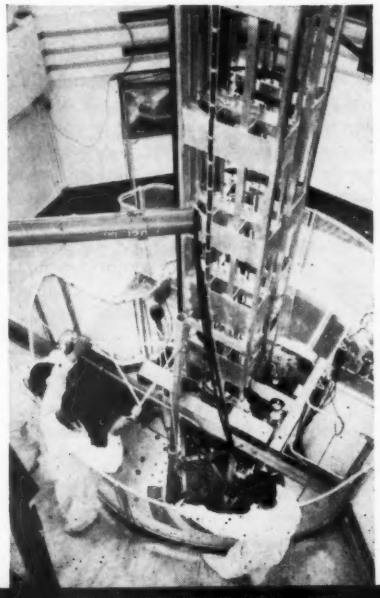


EFFICIENT DESIGN. The experimental facilities and one of the two thermal doors with its elevating mechanism

The radiation fluxes available at 5MW power level are $4 \times 10^{13}/cm^2s$ thermal neutrons at the core centre, 10^{13} maximum in the experimental holes and between 2×10^{10} and 2×10^{13} in the thermal columns.

Extensive effluent treatment plant, employing filtration and ion-exchange, is included within the reactor area for processing water from the secondary cooling circuit which is returned to the adjacent Aldermaston Lake. As this water eventually flows out into the River Kennet and on into the Thames, particular interest is being taken in checking any possible low radiation effects on the fish and bird-life using the lake. In addition to the local authorities, the Ministry of Agriculture and Fisheries, the Kennet and Thames Conservancy Boards, the Port of London Authority, the Metropolitan Water Board as well as the AEA collaborate with AEI and take part in regular discussions and investigations.





THE REACTOR TANK. Above, the core lattice and fuel element storage compartments seen through the shielding water. Right, manual loading of the fuel elements

A first-hand report of work in progress in the new Atomic Power Centre at Whetstone

Nuclear research by English Electric

THE Atomic Power Centre at English Electric's Whetstone works, officially opened by Lord Mills on July 24, provides new and excellently equipped facilities for a division of the company which was formed in 1954. Since then the company state that the staff has grown to a strength of over 800, the majority of which are qualified, with an expenditure approaching £M2 per annum. The work covers research, development, design, construction and commissioning of nuclear stations and NUCLEAR POWER was recently invited to see the laboratories. Problems being tackled cover final design and construction of Hinkley Point, designs for the export market, preparation of tenders for Dungeness and Sizewell, and preliminary development towards an AGR, as well as fundamental research. In all this close collaboration is maintained with Babcock & Wilcox and Taylor Woodrow and some of the work is done under the auspices of the Nuclear Power Collaborative Committee of the four consortia.

Following the agreement with Atomics International (*Worldview*, July) English Electric staff are undergoing training in the USA for three or four years but work on organic moderated reactors at Whetstone is now getting under way.

Giving theoretical backing to all research and development work at the centre is an impressive computer section, comprising the digital machine Deuce and two analogues designed and built at Whetstone—Pluto and Mars. A third analogue, Saturn, is due for completion in 1960 when it is expected to be the largest in Europe.

Pluto is a four-plane reactor simulator, containing 100 amplifiers in a fixed circuit, used for transient and fault analysis of Hinkley Point and other GCR systems. Safety problems such as complete failure of blowers or ducting can be dealt with, and the design of the Hinkley Point fuel element sleeves was initiated on Pluto. Mars is a more flexible, general purpose machine with 200 amplifiers, operable as a whole or in two parts. It is used for similar but more complex problems to those soluble on Pluto and has improved overall accuracy. Now one-sixth complete, Saturn will contain 1512 computing amplifiers in 6 banks of 252 which can be used separately or coupled to any or all of the others. Among the problems which will be tackled with Saturn are reactor instabilities, power station control, and analysis of 3-dimensional stress problems.

No irradiation facilities nor any hot handling cells have yet been installed at Whetstone, the company being able to call on the UKAEA for facilities of this type.

A great deal of effort in the Research and Development department is devoted to designing and testing fuel elements, and in the newly commissioned toxic laboratories complete prototype elements can be produced from billet in the form of bars, tubes and plates. For this there are facilities for melting, casting, rolling and swaging, quenching (water and salt bath), annealing, canning, and helium filling. Both magnox/uranium and Be/UO_2 elements will be made and tested for mechanical strength in a battery of furnaces.

Also in the toxic area is a beryllium laboratory where experiments are in progress on stress-rupture, creep, corrosion and its sensitivity to water content in the atmosphere, and fusion and pressure welding. Fundamental work on UO_2 includes measurement of conductivity by radial heat flow and factors effecting it such as grain size and thermal shock.

In the materials division the search goes on for metals and ceramics which will stand up to reactor conditions. Magnesium alloys, zirconium alloys, steels, and all reactor materials are tested, in some cases up to 15,000 hours, for their mechanical and chemical properties in carbon dioxide atmospheres at temperatures up to 400°C for gas-cooled reactors and

Complete fuel elements are tested in these furnaces for up to 5000 hours at maximum temperatures of 500°C. To simulate stacking conditions each element is loaded at the top and tested for bowing

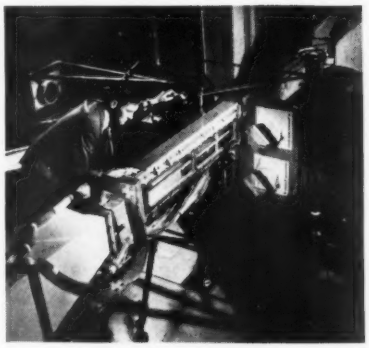
Hot rolling facilities form part of the fuel fabrication shop where prototype elements can be made from billet

at higher temperatures for the AGR. (This extensible temperature range is characteristic of a number of rigs in the Centre so that the same apparatus can be used for GCR and AGR work.) This work has already produced an improved canning material for second-round GCR's—a magnesium-zirconium alloy already on the market which shows improved mechanical properties and equal corrosion resistance.

One of the most interesting corrosion problems is the effect of impurities in the cooling pond water on heat-treated fuel element cans. Two large test rigs and one laboratory scale experiment have shown that after 100-day tests chloride corrosion can be severe. This could be a problem for ponds exposed to sea spray. The attack is more serious on the fins than on the can body, probably due to the effect of machining.

In the new graphite laboratory, which is only just starting up, the programme will include work on flaw detection, methods of joining, and effects of irradiation. For the latter irradiation facilities at Leicester Technical College will be used. Other ceramics under study are gadolinium and samarium oxides for use as control rods and AlO_2 and MgO as structural materials.

In the heat transfer laboratory there are two atmospheric rigs for preliminary sorting by relative performance of fuel can designs and one in which CO_2 is circulated at 200 lb/sq. in. and 400°C. In two months this temperature will be stepped up to 500°C and the flow doubled, and another pressurized rig added.



Basic heat transfer studies by optical methods are performed in the mechanical engineering division using a glass wind tunnel and a Mach Zender interferometer

Another rig measures interface heat transfer from the fuel to the canning surface. This uses a uranium cylinder 1in. dia. and 1in. long and a Magnox specimen inside a vacuum bottle. Heat transfer is measured for varying pressure on the interface. A critical factor is the surface finish of the fuel, but although the specimens are ground and actual fuel bars are turned, it seems that experimental results are applicable owing to the fact that the can is pressurized on to the fuel. In the same laboratory is a sleeve conductance rig used for testing sleeving materials for Hinkley Point and also for testing the efficiency of possible insulators for use in an AGR.

Bearings and lubrication problems are being studied on an ad hoc and semi-fundamental basis in the engineering laboratory. Oils and greases are not in the programme because of their radiation sensitivity and work is concentrated on graphite, molybdenum disulphide and other inorganic lubricants. Temperature limits are 150-400°C at the moment but the sights are set higher than this. Wear of ball-bearings under radial and axial loads is measured by weighing and microscopy, including electron microscopy. In components subjected to the highest radiation, such as fuelling machines, burst slug detection gear and certain valves, the aim is to use no lubrication at all. Recent work has shown that this may be possible by using races with the metal cage of the same hardness as the ball bearings.

Instruments for measuring fuel element temperature are also tested in this division and the system chosen for Hinkley Point has been tested here for 1000 hours. It is a thermocouple method consisting basically of two contacts, one in the fuel element and another in the moderator, held in electrical contact by a spring. Here also the control rod gearbox has been tested under reactor conditions. Its efficiency—an important parameter in emergency shut-down calculations—has been found to be 89%.

Although not a part of the Atomic Power Division, the Mechanical Engineering Laboratory is making an important fundamental contribution to the company's nuclear activities. The mathematics group is using a Deuce digital computer as well as the three analogues for problems such as the effect of control rod penetration on reactivity and calculation of the building frames for Hinkley Point. Stress analysis covers the pressure vessel support skirt and the gas circuits. Vibration investigations on control rod chutes and nests of bent tubes for the b.s.d. gear are also in progress. For fundamental heat transfer work, an interferometer tunnel is used comprising an accurately machined glass wind tunnel and a Mach Zender interferometer.

Complementary to the research and development on Hinkley Point is testing some of the completed gear. In an 85ft pit in the fabrication area the fuelling machines will be tested under full working conditions (except radiation). A scaled-down reactor model will be built

Mars, one of two analogue computers already in use, is a general purpose 200 amplifier machine used for Hinkley Point design problems including safety conditions

in it comprising a 5ft dia. vessel with 39 channels, in 16 of which the carbon dioxide flow can be used. Tests on control rod operation and fuel element withdrawal systems will be performed on two more pits, each 35ft deep.

Although Whetstone is predominantly a design and development centre, the company have decided to install their graphite machine shop there in order to maintain the necessary contact with the analytical section. The moderator, tile and reflector production line is already in operation in strict clean conditions. About 150 moderator blocks are being produced per day at the moment, but this can be stepped up to one per 1½ mins Automatic machine tools and materials handling are a feature of the shop with a punched card system for accurate and prompt material control.

In the toxic laboratories fuel element materials are tested for their heat transfer properties

New Product Survey

PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

NUCLEONIC INSTRUMENTATION

single chassis system

For proportional counting, ionization and fission chambers, and utilizing a single chassis, Hamner Electronics combine a basic non-overload amplifier and a highly regulated, low voltage power supply with a differential discriminator, plus an independently controlled integral discriminator. The Hamner N-354 Preamplifier is available as an adjunct to the system and may be easily cabled to it. Rise-time is less than 0·2 microsecond and linearity in the 0–100 volt range is better than 0·1% into loads greater than 10K.

The integral discriminator provides a good method of monitoring the total count or the count above any predetermined level while carrying out the differential pulse height analysis with the differential discriminator. It has a resolution of 1·5 microseconds and a linearity of 0·5%.

The pulse height analyser has a resolving time of 1·3 microseconds, a base line range of 0–100 volts and a window width of 0–10 volts with larger voltage ranges optional. The base line stability is less than 50 mV per day. The integral discriminator has a resolution of 1·5 microseconds and a linearity of 0·5%. The N-354 preamplifier employs a feedback amplifier having a gain of approximately 25 with fast-rise-time output pulses. Input polarity is positive or negative Maximum rise-time is 0·1 microsecond.

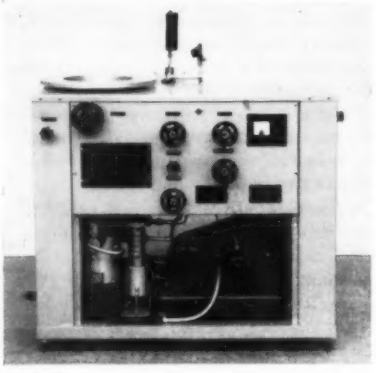
Tick No 208 on reply card

LEAK DETECTON

vacuum pumping system

Edwards High Vacuum have produced test equipment for heat exchanger elements and complicated pipe-work met with in nuclear projects. The 9TO1 unit consists of a panelled metal framework into which is mounted a vacuum pumping system. The instrument panel on the front of the unit contains the valve controls, leak detection and vacuum gauge control unit.

The pumping system comprises a primary oil diffusion pump, 903B backed by a secondary diffusion pump, 203B, both these pumps are, in turn, backed by a 1SC450 rotary vacuum pump. This system is provided with valves to isolate the workpiece from the diffusion pumps; to permit the test piece to be evacuated to a pressure of below 0·1 torr by the mechanical pump prior to the use of the diffusion pumps; and so that a large test piece may be evacuated to a pressure below 0·001 torr by the primary diffusion pump and the mechanical pump without submitting the secondary diffusion pump to a large gas throughput and consequently contaminating the interspace pipeline. Other valves permit the mechanical pump to back the secondary diffusion pump for standard pumping procedure; govern the throughput of gas between the two diffusion pumps to offer the optimum leak testing pressure in the interspace; make adjustments to the interstage pressure; admit air to let the test piece return to atmospheric pressure at the conclusion of each cycle; vary the hydrogen concentration in the interspace pipeline. A 'Speedivalve' is fitted for interspace pipeline isolation purposes.



Specially designed for testing large pressure vessels and banks of pipework, the Edwards High Vacuum 9T01 unit has separate 'roughing' pump facilities

For measuring vacuum a B4 thermal (Pirani) type gauge is fitted, together with a DT1 discharge tube. Two gauge heads are provided, one mounted in the pumping line to give indication of pressure in the component being tested, while if the hydrogen/pirani leak test technique is being used, the other head will be mounted in the interspace between the diffusion pumps to act as a detector.

Two types of leak detector gauges are commended for use with this pumping system, the LT6 having a sensitivity of 10^{-2} lusecs used in conjunction with the M6A Pirani gauge head and the LT4 which is far more sensitive being able to detect leaks in the region of 10^{-5} lusecs.

Tick No 209 on reply card

BOOSTER RELAY

speeding valve operation

A booster relay, known as Model 61H, has been introduced by Sunvic Controls which improves design of process control loops by making it possible to increase valve stroking speeds considerably without loss of stability.

Major time lags in any automatic control loop occur at the diaphragm control valve, where considerable volume flows have to be handled which can, however, be reduced by using a valve positioner incorporating volume amplification but time constants will still average approximately 10 secs. Also volume amplification can lead to instability and oscillation.

Using the new relay in conjunction with a Sunvic high precision valve positioner, it is possible to stroke a valve fully in 1·5 secs. without any tendency to oscillation. A high degree of stability is achieved because the relay incorporates an adjustable damping feedback circuit which permits tuning response to any particular circuit.

The model 61H will accept input pressures up to 100 lb/sq in., and will work in ambient temperatures from −40°F to +180°F. Dead spot is within 0·05% of full scale, linearity within 0·4% of full scale and reproducibility, when used with a valve positioner and with 4% valve friction, is within 0·1% of full scale.

Tick No 210 on reply card

REMOTE CONTROL

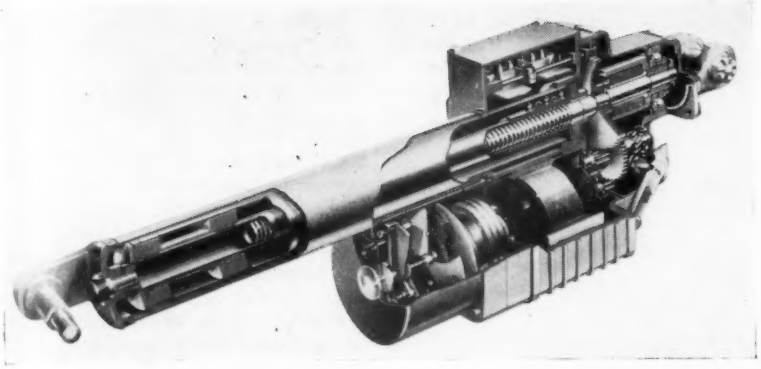
electro-mechanical actuator

The Series 300 electrically-powered actuator by Teleflex Products is basically an electro-mechanical screw jack.

The operating motor is normally wound for a 3-phase 50 cycle 400 volt supply, but motors for other voltages can be supplied. Full load current of the motor is less than 1 amp. A low voltage system—48 volts—is used for signalling to the control room and for the indicating lamps, and a 12 volts supply is employed for the indicating system. The actuator can be operated manually in the event of a mains failure, a plug-in handle being provided.

Power output can be set to any predetermined value and may be varied between 40 and 4000 lb. The standard stroke is 12 in. and ram speed 32 in./min. An overload device automatically stops the actuator and switches off the supply in the event of a load higher than that specified being thrown on the actuator. Cam-operated limit switches are provided for either direction. They are fully enclosed and visual indication of direction of travel is given through a window. A standard fitting is a twin disk brake, electrically released, to check over-run and provide instant and positive locking at any position of the stroke.

Some of the more common applications of the actuators are: operation of



In the **Teleflex 300** actuator the mechanism remains clean at all times and free from fire risk. The thread is fully protected by a steel outer shroud, a wiper seal between end cap bearing and push rod. The casing is of stove-enamelled corrosion-resisting steel and aluminium

groups of valves from a centre control panel: the operation of valves, dampers etc., which are normally inaccessible; remote control of equipment in areas which are dangerous to life, for example in chemical and nuclear engineering etc. The actuator incorporates its own transmitter and position signals are relayed to the instrument panel without additional outside linkages. The weight of the unit is only 56 lb, the overall length 35 in. and the width 5 in.

Tick No 211 on reply card

NEUTRON COUNTING

foil service available

Accurate, reproducible spectral determinations are now possible by using a system of neutron detection foils developed by Aerojet-General Nucleonics. Cross calibration and standardization of fast neutron data are obtained by measuring the spectrum in six energy increments:

1. Thermal fluxes are measured with gold or cobalt foils.
2. Neutron energies greater than 1 keV are measured by plutonium-239 foils.
3. Neutron energies greater than 1·5 MeV, by uranium-238 foils.
4. Neutron energies greater than 2·9 MeV, by sulphur-32 foils.
5. Neutron energies above 5·3 MeV are measured by analysing the products of the (n,p) reaction on aluminium-27 foils.
6. Energies greater than 8·6 MeV, by analysing the products from the (n,α) reaction on aluminium-27 foils.

A boron-10 shield is used to protect the fission foils from thermal neutrons during irradiation. Cadmium covers are available for use with the gold and cobalt foils for determining the cadmium ratio. Sulphur foils are repackaged in 'cold' aluminium after their irradiation, thus eliminating the possibility of mistaking certain reactions in aluminium for those in sulphur.

These accessories, together with high-precision counting equipment and Aerojet technical services, are now available to purchasers of either individual items or complete foil sets. Irradiated, calibrated foils will be supplied for cross-calibrating the user's counting system with the Aerojet reactor-and-counter complex. Or a calibrated detector and sample holder can be used. The detector includes photomultiplier tube, cathode follower, and cables; it is delivered ready to use with amplifier and scaling equipment. If desired, Aerojet will handle the entire spectrum analysis, including preparation of foils, counting and data reduction.

Tick No 212 on reply card

THE NANOSCOPE

sampling fast waveform

Developed by the Atomic Energy Research Establishment, Harwell, primarily for use with scintillation counters, this auxiliary unit will, when connected with an ordinary laboratory oscilloscope, permit the observation of very fast repetitive waveforms of the order of a few nanoseconds (10^{-9} second) duration.

Manufactured by Lion Electric Developments Ltd., the Nanoscope operates by sampling the fast waveform with very narrow pulses at a number of points. This results in the production of a series of pulses, stretched to render them visible on a normal oscilloscope of restricted bandwidth, which are proportional in amplitude to the corresponding ordinates of the sampled waveform. These ordinate pulses are brightened at their peaks, thus tracing the fast waveform as a series of dots on the oscilloscope.

Circuits within the unit provide for the sampling of the waveform at progressively later points, and ensure that once a sampling has been made it is not possible for the sampling circuits to be triggered into action again until the first sample has been displayed on the screen.

In order that the sampled pulses may be centred on the screen, means are provided to delay the sampling pulse until the time base sweeps have started and have reached the appropriate point for the display. Coarse and fine delay adjustments are provided for this purpose. The latter is a helical potentiometer with 1000 divisions, the whole of its range being equal in delay to twice the time-base sweep. Since this can be set to as low as 50 nanoseconds, it follows that each division of the fine delay potentiometer corresponds with 0·1 nanosecond. The instrument is therefore capable of measuring very short intervals in time. The intrinsic rise time of the device is somewhat in excess of 2 ns.

The equipment is provided with a probe which, with range switches on the main unit, gives four settings for input voltages from 0·5 V to 30 V. An internal square-wave generator enables the amplitude of the waveform being examined to be checked to within 5%.

Tick No 213 on reply card

COLD BOX INSTALLATION

for low temperature work

Research and Control Instruments Ltd., sole distributors of Philips scientific equipment in the United Kingdom, announce the introduction of the Philips Cold Box installation. Believed to be the first of its kind in the world, it has a net content of about 400 litres for temperatures down to minus 160°C. Refrigerating capacity at minus 100°C is 4400 Btu/h and 2560 Btu/h at minus 160°C.

The unit is cooled at any preset temperature by the circulation of cold gaseous air from a specially-designed head of the Philips gas refrigerating machine.

The temperature control system consists of a resistance thermometer and a phase-sensitive relay unit; and for the recording and automatic controlling of the box temperature an electronic temperature recorder, a programme transmitter, and a multi-point potentiometer recorder are available, in accessory form.

The installation can also be made suitable for the production of liquid air during the periods that cooling of the box is not required by the addition of a special ice separator, and liquid air delivery pipe.

Among the applications for which the cold box installation is suitable are preservation of chemicals and materials; low temperature treatment of metals, shrink fitting; prevention of ageing of aluminium and magnesium alloys; chilling of stainless steel; environmental test-

ing of electrical components; and low temperature chemistry.
Tick **No 214** on reply card

TWO-PRESSURE VALVES

with automatic kick-in

A range of pneumatically operated two-pressure valves for hydraulic control have been introduced by Hunt & Mitton Ltd. The valve raises a ram on low pressure, and when the press is closed, the high pressure is admitted immediately through the automatic high pressure inlet valve. If required, the high pressure 'kick-in' may be delayed for a pre-determined period by means of a subsidiary diaphragm top on the high pressure inlet valve. This valve will close immediately pressure is released from the ram, thus preventing the loss of valuable high pressure fluid to drain.

The valve may be operated through a manual Pilot Valve or through an electric timer.

Seat sleeves and seats are made from stainless steel hardened to 500 to 550 Brinell, valve disks are of stellite, with the stems of hardened K monel, hard chrome plated, to ensure smoothness of operation and which are in hydraulic balance. The ports in the seat sleeve are so spaced to prevent loss when the stem is moved from one seat to another. These valves are suitable for use with oil or water for working pressures up to 4000 lb/sq in., and are made in sizes ¾ in. to 3 in.
Tick **No 215** on reply card

HIGH SPEED DECADE SCALER

nucleonic and X-ray counting

The Hamner N-270 rack mounted Decade Scaler is especially suitable for use in monitoring applications in the nuclear research field, reactor water supply systems, X-ray instrumentation, analytical chemistry and the petroleum

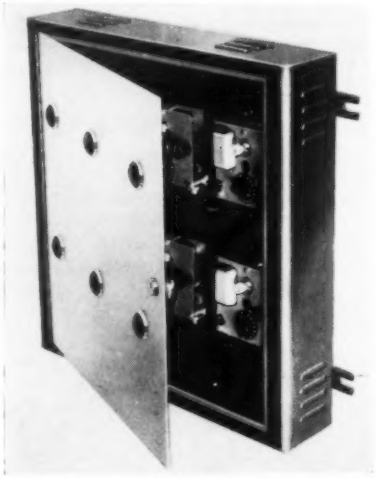
Very clear presentation is a feature of the Hamner N-270 decade scaler employing 6, 7 or 8 DCU assemblies

industry research laboratories and refineries. The unit provides a choice of 6, 7, or 8 plug-in assemblies of the DCU type and features a resolution of 1 microsecond for pulse pairs. Preset count is 10, 100, 1K, 10K, 100K, 1M, 10M and 100M, when 8 decades are used. All controls are on the front panel. High-speed print-out or manual read-out is available and completely remote operation is provided through electronic gating.
Tick **No 216** on reply card

CENTRALIZED LEVEL CONTROL

distant probe location

A development of Fielden Electronics' Tektor Minor level controller enables up to 150 feet of coaxial cable to be used between probe and unit. Multiple construction of electronic units permits centralized or grouped indication of level.



Centralized level indication is provided by six Fielden Tektor Minor electronic units built into one case—the probes may be any distance up to 150 ft from the indicator

The increase in interconnecting cable length means that the unit may be conveniently situated at ground level for ease of access or maintenance or if centralized level control is required, all electronic units can be brought together from different parts of a plant and housed in one case. The interconnecting coaxial cable is supplied with the instrument and no other cables are required from probe to unit and only one mains supply cable runs to the multiple unit. With the Fielden capacitance system of level control there are no electronics at the probe end on the container.
Tick **No 217** on reply card

NEUTRON SHIELDING

boron- or hydrogen-loaded board

William Mallinson Ltd. announce a new shielding material known as *Hydrobord*. It is manufactured in two main forms, Hydrobord F for fast neutrons and Hydrobord T for thermal neutrons, or it can be supplied as a combination of both.

Hydrobord T contains approximately ·12 g elemental boron per cm² per ⅛ in. thickness. At this boron loading it has an attenuation factor of 85. Density is approximately 104 lb per ft³. It is manufactured in sheet form from which it can be easily laminated or machined into various shielding structures. Hydrobord F is designed to provide high hydrogen content evenly dispersed in mass. It is made in block form to an approximate size of 4 ft 8 in. × 2 ft 6 in., from which larger structures can be built up. Weight is 83 lb per ft³, thermal conductivity 0·2 kcal per mho. The approximate chemical composition is $C_2H_{21}O_9$. This is a rigid, stable material easily machined and of considerable strength. Its uses vary from such things as refuelling machines to small shielding plugs.

Hydrobord FT, for both fast and thermal neutron shielding, is a combination of the above two. Proportions can be easily adjusted to requirements.
Tick **No 218** on reply card

IN BRIEF

Vibrator. A rotary electric vibrator manufactured in four sizes has been introduced by Sinex Engineering. Consisting essentially of a squirrel-cage motor carrying out-of-balance weights at both ends of the rotor shaft, it is more compact than previous models and dustproof. Centrifugal forces varying from 300 to 7600 lb can be produced.
Tick **No 219** on reply card

Gaussmeter. A new precision instrument, the model G-501 from Harvey-Wells Electronics, USA. Accuracies to within 2% are claimed for rapid measurements using charts converting counter indications directly to gauss. It has a modulation sweep range of zero to 20 gauss, and field measurements between 300 and 20,000 gauss using standard probes, are readily obtainable.
Tick **No 220** on reply card

In miniature. A new range of panel-mounting 240° scale miniature instruments with 2 in. and 2½ in. dials is announced by Crompton Parkinson. A particular feature of these d.c. moving coil instruments is the inaccuracy limit of ± 1%.
Tick **No 221** on reply card

Gauge tester. Budenberg Gauge's new model the *Ranger* offers a high degree of accuracy on pressure readings between 10 and 8000 lb/in.²
Tick **No 222** on reply card

Dry film. Acheson Colloids are now marketing their new range of resin bonded dispersions of PTFE under the trade mark *Emvalon*. The makers claim a significant advance in the technique of dry film lubrication and surface coating.
Tick **No 223** on reply card

INDUSTRIAL NEWSDESK

GETTING READY FOR SEA. Westinghouse Electric Corp. has built a complete simulator of the NS Savannah's nuclear controls. The trainees are able to go through all the operations of start up, stand watches, emergency drills and perform all functions connected with the reactor

Centralized reprocessing

In August, Vitro Engineering Company, a division of Vitro Corporation of America, was awarded a $M4·3 contract by the United States AEC, to design and engineer a new facility at the Hanford Works for the processing of commercial power reactor fuels. It is estimated that when completed, the entire project will cost about $M6 and should be ready to receive fuel elements by early 1961. The plant will be capable of handling any design and shape of fuel elements, including oxides and alloy cores clad with aluminium, zirconium and stainless steel. Elements will be received in shielded containers, stored in water, dismantled mechanically and chemically treated in preparation for processing by solvent extraction in the existing Redox facilities.

The new plant will be operated by General Electric as part of the existing AEC-GE contract covering the Hanford Atomic Products Operation. Under the present power programme, GE is expecting to receive from 50 to 150 tons per year of highly diversified fuel materials with up to 5% U-235 enrichment.

Australia develops own electronics

As a result of work by the Technical Physics Section, at Lucas Heights, of the Australian Atomic Energy Commission (AAEC), a transistorized scaler has been designed and is going into production for approximately one-third the price of a comparable imported unit. The first batch of these scalers are being made by Industria Manufacturing Engineers Pty. Ltd., at Sutherland, under contract to the AAEC. The Commission is investigating the possibilities of making these and other instruments designed at Lucas Heights available to industry and laboratories throughout the country. To implement this work, several new buildings are under construction, costing some £600,000, to enable the experimental and workshop facilities to be expanded.

Preference for German fuel

At the request of the Japan Atomic Power Institute, six Japanese trading companies presented, in July, estimates from foreign groups for the manufacture of natural uranium fuel for the Japanese No. 1 Domestic Reactor. This 10MW plant is at present under construction at Tokai Mura and is scheduled for completion by the middle of 1961.

The fuel required consists of 270 uranium bars, 2·65m long and 2·5cm in diameter and is to be fabricated from 3-tons of uranium supplied by the IAEA and 3-tons by the Japanese Atomic Fuel Bureau; it is the IAEA material which is the subject of the present proposals. Originally six estimates were submitted —Atomic Energy of Canada Ltd., Degussa (Germany), and the US companies Metals & Controls Corp, Sylvania-Corning Nuclear Corp., The Clevite Corp., and Nuclear Metals Inc., of which the last two subsequently withdrew their tenders. On technical evaluation only, Degussa's proposals were considered to be the best. The Institute is now investigating the costs and relevant commercial aspects. It is anticipated that eventually the Japan Atomic Power Institute will also seek foreign aid in the fabrication of the fuel elements from the material supplied by the Atomic Fuel Bureau.

Anticipating the new regulations

The first commercial radiation monitoring and tracer service in the UK has been introduced by Ekco Electronics Ltd. It aims at assisting industry in three ways: by site surveys and testing sources of radiation, to meet the requirements of the impending Factories (Ionizing Radiations) Special Regulations; measuring radioactivity in air, water and sewage for Public Health Authorities; and carrying out tracer experiments for industrial and scientific research by employing Ekco personnel and equipment for any specific project.

Elliott Nucleonics Ltd. has now inaugurated a new advisory and supply service for any concern that uses radioactive materials on such a scale that installed monitoring equipment is a practical consideration. Both these services will be of assistance to all branches of industry in meeting the new regulations when they come into force later this year.

More sodium reactor work

The United States AEC awarded, in the middle of August, a contract worth more than $M1½ to ALCO Products Inc. for the final design and fabrication of a sodium-to-sodium heat exchanger and a sodium-to-water steam generator; these components are scheduled to be completed by December 31, 1961. This contract follows an initial award in 1958 to ALCO for the preliminary design of heat exchanger components for sodium-cooled nuclear power plants and is part of the Commission's effort to find less expensive and more reliable heat exchanger units for this type of installation.

At the same time, the AEC issued a contract to Diversified Builders Inc., valued at about $M3½, to construct a sodium boiler plant and integrated fuel cycle facility for the Experimental Breeder Reactor II project (EBR-II), at Idaho. This work covers the third major construction phase of the $M29 reactor facility and the award was made after the apparently lowest bid of the eleven proposals submitted was rejected.

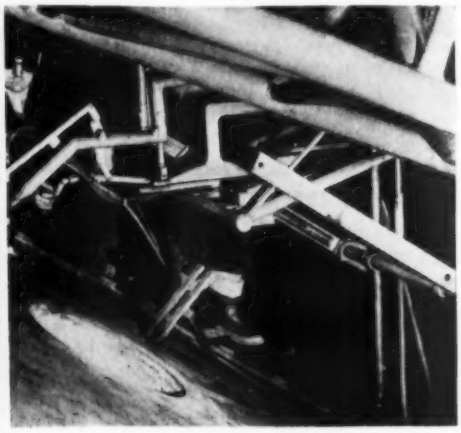
Large manipulator sales

Three further orders for heavy-duty power-operated manipulators, worth about £40,000, have been received by The General Electric Co. Ltd. Each of these three machines, one for AERE, Harwell, one for Japan Atomic Energy Research Institute at Tokai-Mura, and one for the Swedish A/B Atomenergi's Studsvik Research Station, will be used for remote handling of irradiated fuel elements. While basically similar to the first unit installed at the AEA's Wind-

scale establishment some twelve months ago, certain detailed improvements will be incorporated. The telescopic tubes which carry the arm and hand of the manipulator are now lowered under gravity; the size of the control console has been reduced; and the 1½ ton electrically driven hoist which forms part of the standard equipment is now mounted on its own separate gantry to give the maximum height of lift.

India's first fuel plant

The Indian Prime Minister, Mr. Nehru, has stated that the fuel fabrication plant, being set up at Trombay, near Bombay, is expected to go into regular operation in September. Most of the equipment has already been commissioned and when production is commenced, fuel elements for the Canada-India swimming pool reactor will be made. Other industrial activities at the Atomic Energy Establishment at Trombay include the manufacture of equipment for measuring radioactivity.



EXACT LOCATION. Used at Bradwell, this Hancock machine accurately locates an oxygen burner for cutting control apertures. After setting up a pintle on top dead centre of the vessel, the complex movements of the burner are generated automatically

UK equipment goes to Italy

'Mine' type precipitators, similar to those that have been tested and approved for installation at Hinkley Point, have been ordered by the Nuclear Power Plant Co. Ltd. from Plessey Nucleonics Ltd., for the Latina nuclear power station. The equipment consists of nine Mark II pneumatically actuated precipitators for the detection of burst fuel elements by identifying fission products in the coolant.

The Italian Comitato Nazionale per le Ricerche Nucleari has purchased a complete electrodialysis stack from William Boby & Co. Ltd. for experiments in decontamination of nuclear effluents. A similar basic research plant has been supplied to A. Reyrolle & Co. Ltd., for metallurgical research.

In each of the charge machines being built by Strachan & Henshaw Ltd., for the Nuclear Power Plant Co.'s Latina and Bradwell projects, three Taylor-Hobson periscopes are installed—one of them connected with a closed-circuit television camera. These show the operator the exact state of the fuel rod and checks that it has been successfully withdrawn. To nullify the effect of radiation on the inner end of the periscope, the window and intermediary lenses are of 'stabilized' glass.

Trawsfynydd's fuelling

Simplification was one of APC's design aims for this plant and to this end all routine operations required on the reactor charge face have been concentrated into a single multi-purpose machine. While only one such unit will be needed to operate the reactor under normal conditions, there will be a duplicate standby machine which will also be available for special tasks.

Each machine, weighing 380 tons and standing over 60 ft high, is moved around the charge face by an overhead crane which is built on the basis of a rigid frame into which the shielding is placed. The frame consists of three long vertical tubes connected at intervals by means of platforms which carry ancillary equipment—the overall structure is designed to facilitate rapid dismantling.

While the principle operation carried out by the composite machine is that of changing the fuel elements, other operations include the changing of the control rod units, flux scanning units and thermocouple fuel elements, and the changing and adjustment of flattening bars and channel gags.

Sources of radiation in the UK

In the Annual Report of the Chief Inspector of Factories for 1958, issued at the end of July, it was indicated that some 500 factories now use radioactive isotopes and the number continues to grow. While about 85 per cent of these companies use sealed sources, it is anticipated that future uses will involve larger units in the kilocurie range—expected applications include cold sterilization of surgical materials and pharmaceutical products, preparation or preservation of foodstuffs and the production of chemical changes such as polymerization reactions.

Iridium 192, in strengths ranging from a few curies up to a maximum of approximately 20 curies, is the most common sealed source for industrial gamma radiography; other sources used for this work are cobalt 60, caesium 137 and thulium 170. The use of thickness gauges using active sources continue to increase in factories and rapid strides are being made in the development of gauges for thicker materials, such as steel plates.

Open sources continue to be used in tracer work, but the increase in this application has not been as rapid as anticipated. A wide range of industries has resorted to tracer techniques, such as using sodium 24 to determine the correct mixing of vitamins in cattle foods; sodium 24 and gallium 72 in cement kilns; radon to check transit time of gases through blast furnaces; caesium 134 to locate getters in television tubes; phosphorus 32 in dye monitors; and gold 198 in cider press filter testing.

More work in US for RN

A new organization, to be known as the Special Atomic Project department, has been set up by Westinghouse Electric Corporation for the procurement of the propulsion plant for HMS *Dreadnought*—the UK's first nuclear-powered submarine. This department will be headed by Mr. William R. Ellis, formerly manager of the power plant section for the Shippingport project, who said that 'besides procuring the atomic power plant equipment for this British submarine, we are also going to train the personnel of Rolls-Royce and the British Admiralty in the design and construction of this plant so that they can build their their own similar plants in the future'

Early in August General Dynamics Corporation's Electric Boat Division was awarded a contract to provide design,

USING SPARK IONIZATION. The first production model of Metropolitan-Vickers MS7 Mass Spectrometer designed specially for measuring minute impurities in solid substances

material and technical assistance for the installation of *Dreadnought*'s propulsion system. It was this company that delivered the *Skipjack* to the US Navy on April 15 this year.

Nimrod contracts placed

During August, the National Institute for Research in Nuclear Science placed contracts, worth more than £430,000, for the materials and manufacture of the magnetic coils required to energize the 7000-ton electromagnet of the 7GeV proton synchrotron, Nimrod. The contracts cover 300-tons of refined copper, in cast bars from British Copper Refiners Ltd., of Prescot; extrusion of the cast copper into hollow rectangular bars by James Booth & Co., of Birmingham; and Metropolitan-Vickers Electrical Co., of Manchester will manufacture the coils from the extruded bars.

In addition, a substantial contract has been awarded to Marston Excelsior Ltd., of Wolverhampton, for the development and supply of a reinforced plastic vacuum chamber. The machine is being built for the institute by the UK Atomic Energy Authority at the Rutherford High Energy Laboratory, Harwell.

Greater use of metals

During the coming year, the US Bureau of Mines are initiating metallurgical studies to improve utilization of zirconium and hafnium minerals and the radioactive raw materials, thorium and uranium. In addition, the Bureau is to intensify research on beryllium and its source materials. Studies will be made to reduce the cost of separating zirconium and hafnium, and determine the effects of irradiation and corrosive conditions. Research will be carried out to extend fabrication techniques of these metals, such as deep-drawing, extrusion and other forming operations.

One of the major projects at present being undertaken by the four research installations of the Bureau is to find a use for depleted uranium. Investigations include its use for cathodic protection, as an ingredient in bearing materials, as a heavy medium in mineral separation, as a constituent of high-strength steels, and as a catalyst in refining shale oil.

Nuclear activities transferred

On August 18 the formation of a new international company was announced jointly by Head Wrightson & Co. Ltd., of Thornaby-on-Tees, and Arthur G McKee & Co., of Cleveland, Ohio. Based on London, the new organization, the McKee Head Wrightson Co., will combine the experience of the two parent concerns, which have been associated together for the past fifteen years in contracting for the steel industry, in the designing, engineering and building of petroleum refineries and chemical plants. This work has previously been carried out in the UK by Head Wrightson's subsidiary company, Head Wrightson Processes Ltd. (HWP), in paralliel with their work on materials testing reactors. With the establishment of the Nuclear Power Division of Head Wrightson's at the Friarage, Yarm, Co. Durham, and to streamline HWP's participation in the new company, all nuclear activities will be transferred to the Nuclear Division and HWP's interests in this field will be run down.

TEST FUEL. A wafer of radioactive uranium dioxide is prepared by Atomics International for a critical experiment

FIRST SHIPMENT. AMF Atomics (Canada) Ltd. have completed 60 uranium oxide fuel elements of an order for 300, each valued at approximately $600, for Atomic Energy of Canada Ltd.

Hot ceramics

Two General Electric scientists, working at the United States AEC's Hanford plant, have designed a carbon arc image furnace and temperatures of 5000°F are achieved for testing ceramic fuel elements. This installation has been so designed that moving or still pictures of the specimen can be made while it is being heated and it is kept under visual observation during all phases of experimentation through microscopes. The heat is derived from an air-blown, water-cooled carbon arc, ray reflected by a parabolic mirror at one end of the furnace to another such mirror at the other end. This second mirror focuses the rays onto the specimen placed in a quartz envelope containing helium.

Widening engineering activities

In Powell Duffryn's annual report, released on August 22, their chairman stated that not only was Powell Duffryn Carbon Products machining graphite blocks for Hunterston nuclear power station, but that additional work had been accepted which will keep this subsidiary occupied well into 1961.

Another member of the Group, Cory Brothers & Co. Ltd., has acquired the share capital of MacCleaster Chemical Co. Ltd. This company manufactures a range of anti-corrosion compositions for metals which not only provide protection

AEA BUYS AMERICAN. The first PACE Analog Computer to be installed in the UK will be shortly set up at Winfrith Heath

against the corrosive effects of atmosphere, sea water, fresh water, electrolytic and galvanic action but which are virtually immune to the attack of hydrocarbons and are resistant to temperatures of up to 500°C.

In view of Cambrian Wagon & Engineering Co.'s entry into the chemical and petroleum industries equipment field, this subsidiary of Powell Duffryn Ltd., has, with effect from July 29, changed its name to Powell Duffryn Engineering Co. Ltd.

New works for pressure vessels

Designed to meet the needs of the nuclear, chemical and petroleum industries, Steels Engineering Installations Ltd., of Sunderland, have brought into operation a new factory. The production shops have been planned to give a very fast throughput of pressure vessels and heat exchangers and, in addition to the normal manufacturing facilities, stress relieving can be undertaken. The inspection facilities include a 4500 lb/sq.in. pump for hydraulic testing and full industrial radiography.

Federal Germany gets accelerator

Financed through the German Atom Ministry, the Max Planck Institute of Nuclear Physics, at Heidelberg, has placed a contract with High Voltage Engineering Corporation for a 10 million-electron-volt research accelerator. This equipment, a tandem Van de Graaff positive ion unit, will be the largest and most powerful of its type and is expected to double the useful range of previous electrostatic accelerators. When brought into commission, late in 1960, it will be used for basic nuclear research on the heavier elements, under the direction of Prof. Dr. W. Gentner.

Mainly discussions

Ottawa. A strong UK delegation attended this year's Commonwealth Standards Conference between August 26 and September 4. The three main technical sessions covered steel, air receivers and crane standards.

INDUSTRIAL NEWSDESK

New York. During the meeting of the Special Committee on Oceanic Research of the International Council of Scientific Unions held between August 29 and September 12, a considerable part of the programme was given over to radioactivity in sea water.

Varenna. Organized by the International School of Physics, at Milan, a course on Plasma Physics will be held between September 2 and 15.

Tokyo. From September 14 to September 16, the Japan Atomic Industrial Forum, Inc and the Japan Radioisotope Association Inc will jointly hold the Third Japan Conference on Radioisotopes.

Geneva. The European Organization for Nuclear Research will, between September 14 and 19, be holding an International Conference on High Energy Accelerators and their Instrumentation.

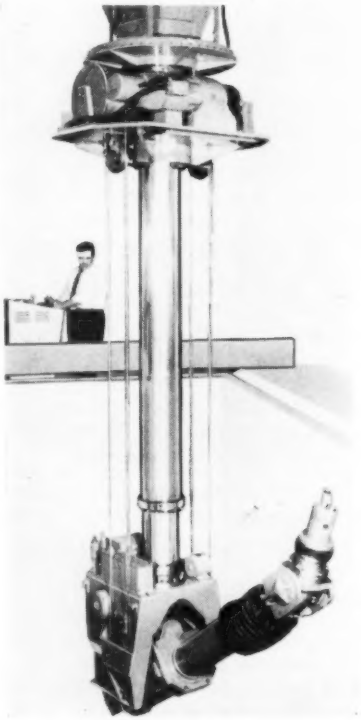
London. 'Operational Research at Work' will be the subject of a one-day Conference organized jointly by The British Institute of Management and The Operational Research Society on September 17.

Vienna. The Third Session of the General Conference of the International Atomic Energy Agency, opens on September 22 and will probably last for two weeks.

Glasgow. The Scottish section of the Institution of Plant Engineers are holding a meeting on 'Basic Electronics in industry and commerce' on September 24.

Leeds. 'Operational research' will be the subject of the West and East Yorkshire section's meeting on September 28.

LARGEST MANIPULATOR. Lifting 5000 lb, this General Mills unit will be used in the US Project Rover for rocket nuclear propulsion development



International exhibitions

Australia. At the Queensland Centenary Show held in Brisbane during the third week of August, models of UK nuclear power stations were included in the British Pavilion.

Sweden. Nuclear power plant equipment will be included in the British section of the St. Eriks Fair in Stockholm, which will be held early in September.

Germany. A French swimming-pool type of reactor will be operated at the 'Atom und Wasser' exhibition to be held in Essen between September 22 and October 18.

France. The Machine Tool Exhibition, which opens on September 12, will be the starting point for a new EMI Electronics' demonstration unit. Later, main industrial centres in Belgium, Holland, Germany, Switzerland and Italy will be visited.

In brief

Isotope branding. Radioactive tantalum has been used by Sandviken Jernverks A/B recently as an identifying material in the production of tubing for two heat exchangers for Sweden's first commercial reactor, which is to be erected at Farsta, south of Stockholm.

More BSD equipment. A contract has been awarded to Plessey Nucleonics for the Burst Slug Detection equipment for the AGR reactor at Windscale. This will be the fifteenth installation of this type of plant that Plesseys have made.

Inspection combination. The interests of Messrs. R. F. Fraser-Smith and Inspection Services Ltd. have been merged and the complete range of non-destructive testing equipment will now be available from Inspection Services.

Continuous monitoring. The US Navy's Department Bureau of Ships has awarded a $135,000 development contract to Tracerlab to produce a small light-weight continuous air particulate monitoring system for use in nuclear submarines.

Far East success. During July, Ekco Electronics Ltd. received orders, valued at some £17,000, from China for scintillation counters, scalers and ratemeters.

To make US equipment. Opperman Gears (Holdings) Ltd. have formed a subsidiary company, LimiTorque Valve Controls Ltd. to make the US Limi-Torque units under licence.

US goes behind the curtain. At the end of July ten executives from American companies made a tour of Soviet electric power systems and equipment manufacturing plants.

Spert III Reactor, Operated by Phillips Petroleum Co. for the U. S. Atomic Energy Commission.

. . . *Used in SPERT-III Reactor*

SPERT-III, the second Special Power Excursion Reactor Test facility now in operation at the National Reactor Testing Station, Idaho, will help provide further valuable knowledge of transient behavior of reactors under various conditions of pressure, temperature, and coolant flow.

Phillips Petroleum Company, conceptual designer and operator of SPERT-III for the U. S. Atomic Energy Commission, selected M & C Nuclear to supply the UO_2-stainless steel fuel assemblies for the reactor.

These fuel assemblies are built to withstand unusually severe conditions. Plates are fabricated to exacting specifications and brazed into assemblies with close channel space limitations.

In addition to SPERT-III, M & C Nuclear has produced UO_2-SS cermet plates for two other large reactors. Its modern facilities and technical know-how permit low cost, quality fuel elements to meet every requirement.

Let us assist you in your reactor program by supplying information, working specifications, and designs. Write directly to our Manager of Marketing and Contract Administration.

The fuel plates, illustrated, were manufactured to the following dimensions and specifications.

Fuel Composition	18.8 Weight % UO_2
Length	37.00″ ± .02
Width of Meat	1.431″ ± .003
Thickness-fuel	0.020″ ± .001
Thickness-clad	0.005″ ± .001

M&C NUCLEAR, INC.

P. O. BOX 898, ATTLEBORO, MASSACHUSETTS, U.S.A.

FUEL ELEMENTS, CORE COMPONENTS, COMPLETE CORES

Tick **No 83** on reply card for further details

They said...

points from papers, speeches, conferences

Assessing potentialities

A rather optimistic view was expressed by Mr. C. M. Watson-Munro, OBE, chief scientist of the Australian Atomic Energy Commission, when addressing the Institute of Fuels at Sydney, in April. He said that when assessing the contribution that nuclear energy could give to the development of Australia, it was necessary to answer three major questions. What are the likely demands, load factor and location during the next few decades? What conventional sources will be available and at what price will their products be priced? What are the costs of nuclear energy at various load factors and various sizes of power plants.

Over the past four years different authorities have made forecasts of likely demands up to the year 2000, all of which result in about the same estimate for Australia, namely 35,000 MW. For nuclear power to provide a worthwhile and economic base load, some 20,000 MWe by the year 2000, it will be necessary to have nuclear power stations feeding in at least 3500 MWe by 1975.

With lower coal costs it is likely that it will be some years after the United Kingdom that nuclear power will be competitive in Australia, but some of the best coals, situated mainly in the Eastern States may have to be reserved for use as industrial carbon. Hydro-electric power could be developed, but this source of energy is likely to be restricted to a few thousand megawatts and is particularly suitable for peak loads.

The overall picture of future Australian power requirements will thus be made up by nuclear reactors supplying the base load; coal-fired stations and hydro-electric plants the peak loads. In terms of output the breakdown will be:

YEAR	TOTAL MWe	NUCLEAR MWe	% NUCLEAR
1975	*10,000*	*3500*	*35*
1980	*13,500*	*5000*	*37*
1985	*17,500*	*7000*	*40*
1990	*23,000*	*10,000*	*43*
1995	*29,000*	*14,000*	*48*
2000	*35,000*	*20,000*	*57*

He then went on to say that 'in any economic comparison it is desirable to clearly state the assumptions used of interest and amortization rates. A more realistic comparison should also include the capital costs of mining (uranium and coal), fuel fabrication (uranium), transport (coal), waste disposal and transmission lines.'

To bring the price of nuclear energy down to an economic level it will be necessary to utilize locally occurring fuels, uranium and thorium, and to employ breeder techniques. Thus 'breeder reactors should be developed by 1975 and while the amount of fertile material to feed a nuclear power producing system of the kind pictured above will depend greatly on the type of reactor, it might be of the order of a few thousand tons of uranium or thorium. To start the breeder system off, a capital investment of fuel would be necessary and the rating of the fuel might well lie between

C. M. WATSON-MUNRO
. . . 20,000 MWe by A.D. 2000

1/3 MWe per kilogram of fuel and 1 MWe per kilogram. This would imply a capital requirement of between 3 and 10 tonnes of fuel which should be made in reactors of the natural uranium type as plutonium from U-238 or U-233 from thorium. To produce 5 tonnes of fuel, about 1000 MWe of such reactor capacity would need to be installed in Australia between 1965 and 1975. There may be areas in Australia, remote from the comparatively cheap fuel deposits in the Eastern States, where such natural uranium reactors could be profitably installed before 1975.'

Implementing the programme

The Australian Atomic Energy Commission's programme is based upon a choice which can be carried through to the reactor experiment stage within the country's resources; not duplicating overseas efforts; a collaborative effort where the AAEC's contribution can be exchanged for results from overseas.

While a wide variety of possible power reactors exist, the AAEC has only been able to examine some of the more promising types. A fairly extensive system of bilateral agreements, including those with the UK, Canada and the US, which provide for the exchange of information and results have already accrued.

There seem to be advantages in having a power programme employing 'reactor systems which are adaptable to smaller units, but which can also supply base load power in large quanta if necessary. A reactor, involving beryllium as moderator and cooling with gases or possibly a liquid metal such as sodium, does meet with these conditions and has been chosen for investigation. The aim is to produce a fuel element capable of a rating of about 1 MWe per kilogram of fuel, a conversion factor of around 1 and a burn-up of approximately 1.' If the Commission can meet this objective with a high integrity fuel element, the fuel costs would be less than 0·1d per kW hour. Good progress has been made in the preparation of fuel element samples and in about eight months' time, the first irradiated samples will be removed from Hifar. Nevertheless it will be several years before the AAEC reach the reactor experiment stage and after which some time must elapse before it is possible to proceed with any power production.

'It is not easy to predict where and when the benefits of atomic energy will come to Australia,' said Watson-Munro. 'However, I feel sure from our experiences, so far, that atomic energy could make as big an impact on the Australian economy as has the discovery of electricity.'

Fusion development

During the 4th International Conference on Ionization Phenomena in Gases at Uppsala (Sweden), in August, Dr. Alan Kolb of the United States naval research laboratory in Washington, announced that he had produced neutrons derived from the fusion of deuterium atoms. Dr. Kolb said, however, that it has not yet been possible to prove that thermal near-equilibrium necessary for fusion had been achieved.

The equipment employed is essentially a tube, 12 in. long and 1·2 in. in diameter, containing deuterium gas under pressure, fitted with magnetic coils to impose limited stability on the gas discharges and supplied with a 30 million watt 'fast' electrical pulse. While being cautious about the temperatures achieved, Dr. Kolb stated that 'probably 10^7°C had been attained in the apparatus.' The most interesting feature of this work is that at least a certain degree of stabilization has been achieved.

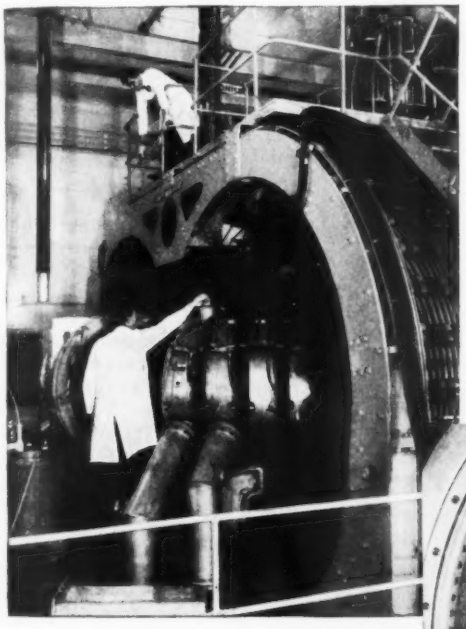
TEDDINGTON BELLOWS

and Nuclear Power

HARWELL PAYS A TRIBUTE

Harwell top research scientists have freely acknowledged * that recent improvements in the operational efficiency of Zeta owe much to the introduction of a corrugated stainless steel liner inside the aluminium 'torus'. Having decided to use such a liner, they turned to Teddington engineers who, out of their experience in adapting their bellows expansion joints to various demands in a wide field of industry, produced exactly what was required for satisfactory running over long periods.

** In a paper read before the I.E.E. on 29/30 April 1959 by Mr. J. T. D. Mitchell of the U.K.A.E.A., Harwell*



In Zeta, experiments towards controlling fusion have resulted in gas temperatures of several million degrees centigrade being achieved for millisecond periods. View showing the torus.

This stainless steel liner has improved operational characteristics and requires less maintainance than the original aluminium liner system. Here is part of the twelve welded sections of Teddington stainless steel bellows tube of wall thickness 0·017″; it has 2½ convolutions per inch of a depth of 0·75″. The bellows is 38 inch bore and the whole toroidal bellows assembly has an axial length of 37 feet and an electrical resistance of 0·02 ohms.

SEND FOR HANDBOOK R. 83

Illustrated descriptions are given of the many and varied problems that Teddington Bellows Expansion Joints can overcome. If you did not secure your copy at the Engineering Exhibition, please write for one.

ZETA

Teddington Bellows are produced in technical collaboration with the Solar Aircraft Co., U.S.A.

TEDDINGTON

STAINLESS STEEL BELLOWS

TEDDINGTON AIRCRAFT CONTROLS LTD. (*Industrial Bellows division*)
Ammanford, Carms. Tel.: Ammanford 2255

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NAMES IN THE NEWS

A new top job in the nuclear field has gone to **Dr. C. P. Haigh,** who at the age of 39 has been appointed director of the Central Electricity Generating Board's Berkeley laboratories. Dr. Haigh, who was awarded his PhD for research in nuclear physics has worked for Ferranti's, Thorium Ltd. (later to become the Radiochemical Centre) and as principal physicist at Barrow Hospital, Bristol. Since 1956 he has been head of the physics section of the CEGB's nuclear development branch.

Dr. C. P. HAIGH to head Berkeley research

Mr. J. B. Adams, 39, has been chosen by the Atomic Energy Authority to be director of their new establishment for controlled thermonuclear research (site at present undecided). During the war Mr. Adams worked on the development of centimetric radar, and from 1946 to 1953 he worked at Harwell on the 110 in. dia. cyclotron. At present he is in Geneva where he is director of the proton-synchrotron group of CERN. It is not expected that Mr. Adams will take up his new post until towards the end of 1960.

Formerly manager of English Electric's overseas atomic projects, **Mr. J. F. Herbert** has now been made general manager export sales. He continues his interest in atomic exports, especially now in view of the recent tie-up with Atomics International to market OMRs.

Changes in the Atomic Energy Authority board have resulted in the appointment of **Air Chief Marshal Sir Claude Pelly,** GBE, KCB, MC, to be member (designate) for weapons. He succeeds Sir William Penney who remains member for scientific research. Sir Claude, who is retiring from the RAF, has been Controller of Aircraft at the Ministry of Supply since 1956.

Sir CLAUDE PELLY takes over weapons

APPOINTMENTS IN BRIEF

Mr. George E. Roth, a New Zealander, has been made director of the International Atomic Energy Agency's isotope division. He succeeds Professor Yoshio Fujioka of Japan.

Mr. C. R. King becomes chairman of the Electricity Council in succession to Sir Henry Self who has retired. Mr. King has been deputy chairman of the Generating Board since its formation two years ago.

Mr. H. L. Russo has been appointed manager of the Italian SELNI project at the atomic power department of Westinghouse Electric Corporation.

Mr. E. Seymour-Semper, managing director of Hancock & Co. (Engineers) Ltd., has been elected president of the Institute of Welding of which he is a founder member.

Mr. R. H. Burdett, nuclear systems engineer of the CEGB's nuclear power branch, has been made deputy director (mechanical) in the applications branch, research development department of the Board.

Mr. R. C. Waugh has joined M. & C. Nuclear Inc. as project engineer for industrial fuels. Mr. Waugh was previously with the metallurgy division at Oak Ridge National Laboratory where he worked on fuel element design and manufacture.

Mr. G. C. Dale is leaving the health physics division of Aldermaston to be physicist deputy in the nuclear health and safety department of the CEGB.

CATALOGUES AND BULLETINS

Fuel elements. Bulletin NCB-1 from American Babcock & Wilcox summarizes and illustrates the manufacture of fuel elements for nuclear reactors. There is also a new bulletin on Babcock & Wilcox swimming pool reactors for research and training.

Tick **No 248** on reply card

Lead. The Lead Development Association have reprinted their popular information sheet 'Simple notes on lead and its uses' which has also been largely rewritten and brought up to date.

Tick **No 249** on reply card

Crucibles. Information on the care and use of crucibles is the subject of leaflet from Morgan Crucible Co. Ltd., who have also issued a data sheet on carbon vanes.

Tick **No 250** on reply card

Zirconium. Leaflet from ICI lists the range of wrought products and standard sizes of rod, bar and billet available in zirconium or zirconium alloy.

Tick **No 251** on reply card

Isotopes. Leaflets from The Radiochemical Centre on clinical radiation sources, labelled compounds and radioisotopes in medicine have text in three languages.

Tick **No 252** on reply card

Inspection equipment. Booklet from P. W. Allen & Co. illustrates and describes a number of items including periscopes for remote viewing.

Tick **No 253** on reply card

Semiconductors. Johnson, Matthey have brought out a concise and informative booklet on semiconductors including a section on Johnson, Matthey materials for semiconductor devices.

Tick **No 254** on reply card

Nuclear graphite. Union Carbide have issued interesting booklet which includes tables showing properties of two grades of reactor graphite and one mould and crucible graphite also properties of materials for moderators and reflectors.

Tick **No 255** on reply card

Organic moderators. Limited copies are available of a literature survey on organic coolants and moderators for nuclear reactors. This excellent publication from Monsanto Chemicals can be supplied to bonafide nuclear engineers.

Tick **No 256** on reply card

Steel machining. Attractively produced book from F. H. Lloyd gives a pictorial survey of lathes and other equipment in course of manufacture.

Tick **No 257** on reply card

Measuring instruments. Booklet from Hilger & Watts describes, with illustrations, their range of autocollimators. Leaflet also available deals with a new neon-type optical digitizer.

Tick **No 258** on reply card

Chemical resistant thermoplastics. Information sheets on items ranging from polythene valves and taps to rigid p.v.c. tubing are available from I.M.P.A. Ltd.

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Uranium foil. Recently published data sheet, NU-7 describes uranium and thorium foil made by M. & C. Nuclear Inc. Foil can be supplied in various thicknesses and in plastic coated or packaged form.

Tick **No 260** on reply card

Finned tube heaters. Illustrated brochure from Hunt & Moscrop describes their range of finned tube heating and cooling batteries. Data on various kinds of finned tube and a steam table are included.

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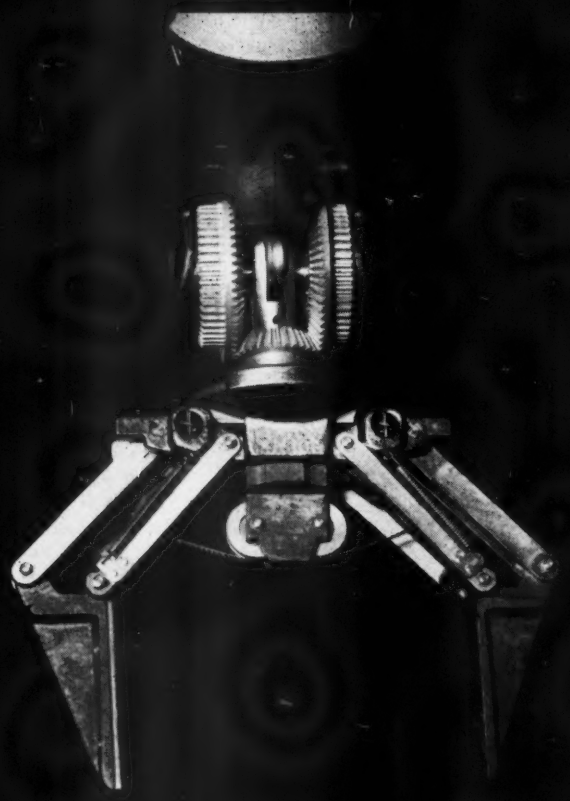

Manipulators

The manipulators used at atomic establishments have to operate under exacting conditions. They are constructed of stainless steel and Kanigen plated aluminium and the plate serves two functions. It resists corrosion and, because of the smoothness of the finish, it also assists in decontamination of the component parts from radio-active material; and the combination of stainless steel and Kanigen plated aluminium reduces the electro potential difference between the component parts. These manipulators, manufactured by Savage & Parsons Ltd., are supplied to users all over the world. Kanigen is used on the aluminium parts of the Tong End assembly and the Ma ‘er Hand assembly.

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Book Reviews

Report on carbon

Proceedings of the Third Conference on Carbon London 1959: Pergamon Press 718 pp Price £7

Due mainly to atomic energy, carbon and graphite have recently emerged from the world of 'black art' and become the focus of intense scientific study. The international meeting-place for research workers is provided by the biennial Conferences on Carbon held at the University of Buffalo. These originated in 1953 largely due to the efforts of Professor Mrozowski. Their interest and scope has broadened with each conference. Thus from a mere 45 pages of print for the first conference, the third conference proceedings have expanded to over 700 pages. It would appear that a more concise style of presentation is required for future conferences if the present pattern of expansion is not to continue.

This book contains almost all the papers presented at the Third Carbon Conference in June 1957. As is now customary, no discussions are reported and this does seem a great loss in such a rapidly developing subject.

Of particular interest to readers of NUCLEAR POWER are several papers on the effects of neutron irradiation on graphite, though it is unlucky that a fire delayed publication until after the report of the 1957 UK/US Graphite Conference.* However, there are many other papers of interest. Indeed they range from the structure and properties of polycrystalline aggregates to studies of single graphite crystals and further still to the properties of large aromatic systems. Carbons and graphites are fascinating because of their diversity and complexity. Here is a book of truly international flavour which gives an authoritative account of recent research on carbon.

M. S. T. Price

* US Atomic Energy Commission Report TID 7565 (Pt. 1)

. . . on accelerators

Proceedings of the 1958 Accelerator Conference Cambridge, Mass., October 14-16, 1958

Sponsored by the High Voltage Engineering Corporation, who specialize in the manufacture of Van de Graaff electrostatic generators, the Conference was concerned largely with applications of this type of machine. The papers presented covered a very wide range, from the measurement of the reactivity of sub-critical assemblies to activation analysis, and from dosimetry to nuclear spectroscopy.

The only paper concerned with new developments in accelerators was one by Dr. Van de Graaff on the tandem electrostatic accelerator, in which he explained the basic principles and suggested that future machines might have three or four stages to obtain particles with an energy of 20 MeV and over. Two papers were concerned with applications of the electron linear accelerator: Dr. Van Winkle gave an amusing description of the tribulations experienced in setting up the first large-scale commercial irradiation plant for the sterilization of surgical sutures, and Dr. Sargent described a time of flight spectrometer using the MIT linear accelerator.

The technical standard of the papers is rather varied; many are excellent, although some authors assume that the reader is conversant with their specialized technical jargon, while others do not seem to be aware of the fundamentals such as the difference between the energy and intensity of a beam of electrons. It is even stated that 'we learned that 2 MeV were required for sterilization' in a paper describing the determination of the thickness of polythene that could be sterilized, there being no reference to the dose given or even apparent awareness that it mattered.

This publication should be of interest to anyone with a spare Van de Graaff, the ability to sift the wheat from the chaff, and a magnifying glass to read some of the illustrations.

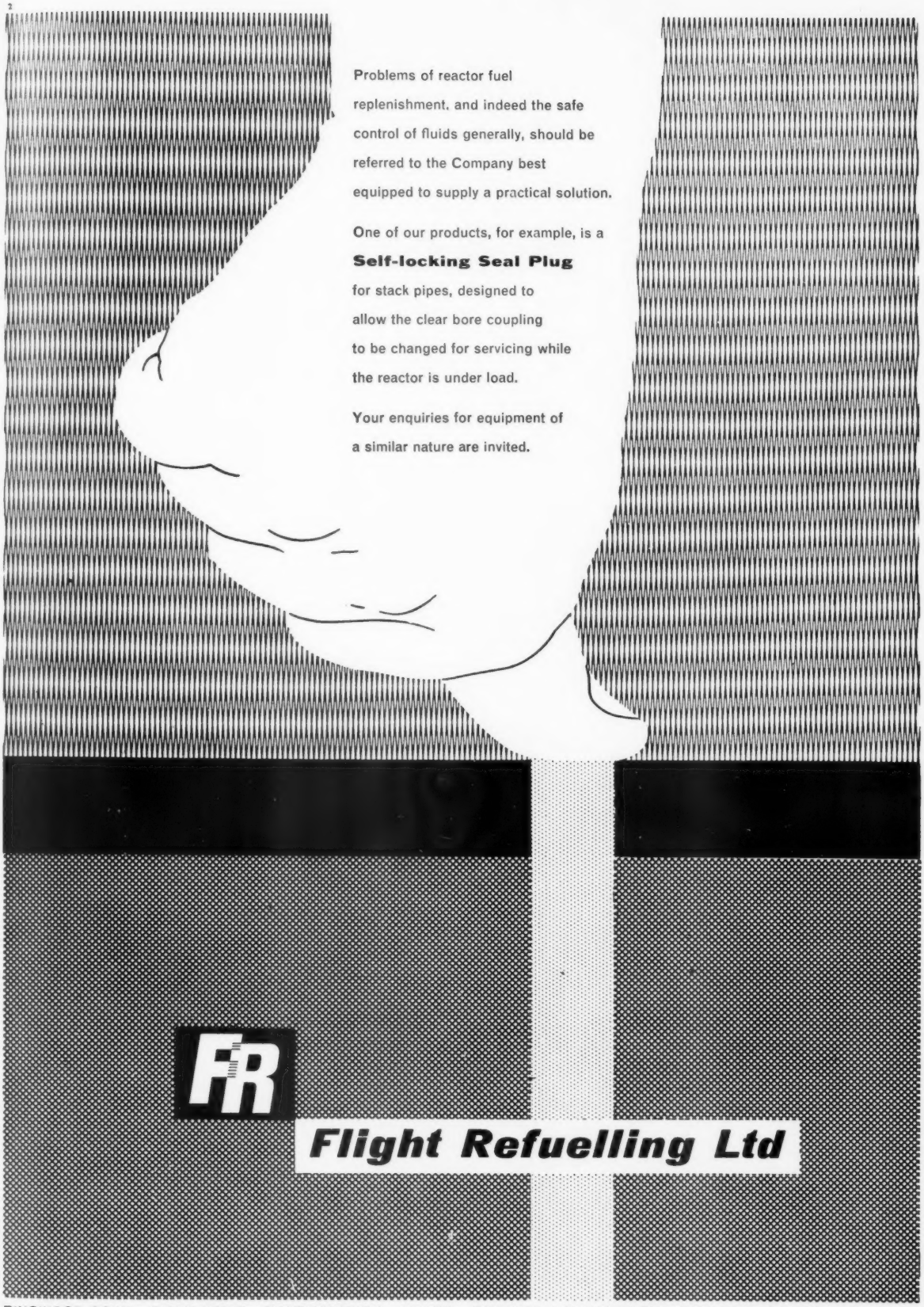
M. C. Crowley-Milling

. . . from Geneva

Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy. Her Majesty's Stationery Office, 1958
Vol. 5 Properties of reactor materials 627 pp £5
Vol. 10 Research reactors 548 pp £6 12s

Divided in two parts, volume 5 covers, first, the mechanical properties and corrosion resistance of materials transparent to neutrons at high temperatures in the coolant environment, and secondly the effect of radiation on both structural and fuel materials.

Nine new high flux research and engineering test reactors, already in operation, are described in volume 10 and progress reports on others are given.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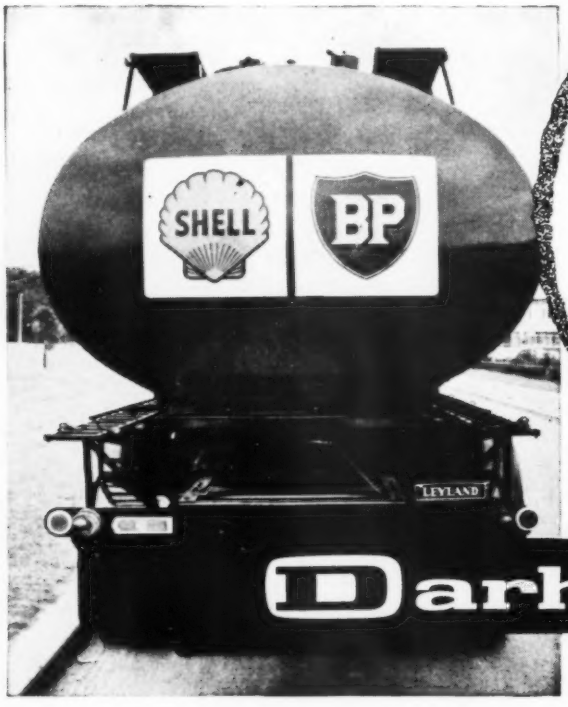

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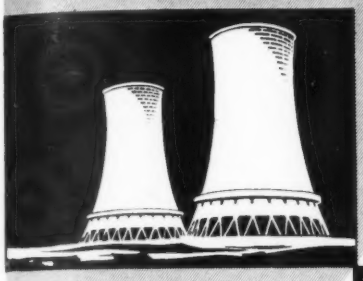
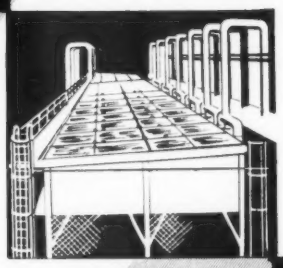
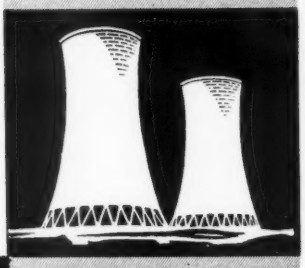


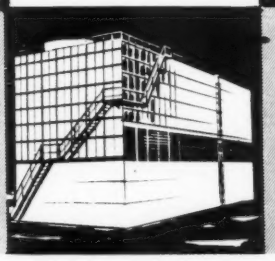
NATURAL DRAUGHT COOLING TOWER

NATURAL DRAUGHT HEAT EXCHANGER





MECHANICAL DRAUGHT HEAT EXCHANGER



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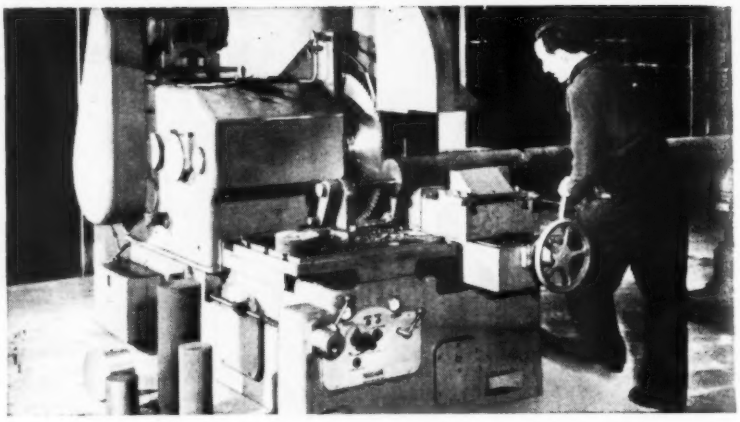

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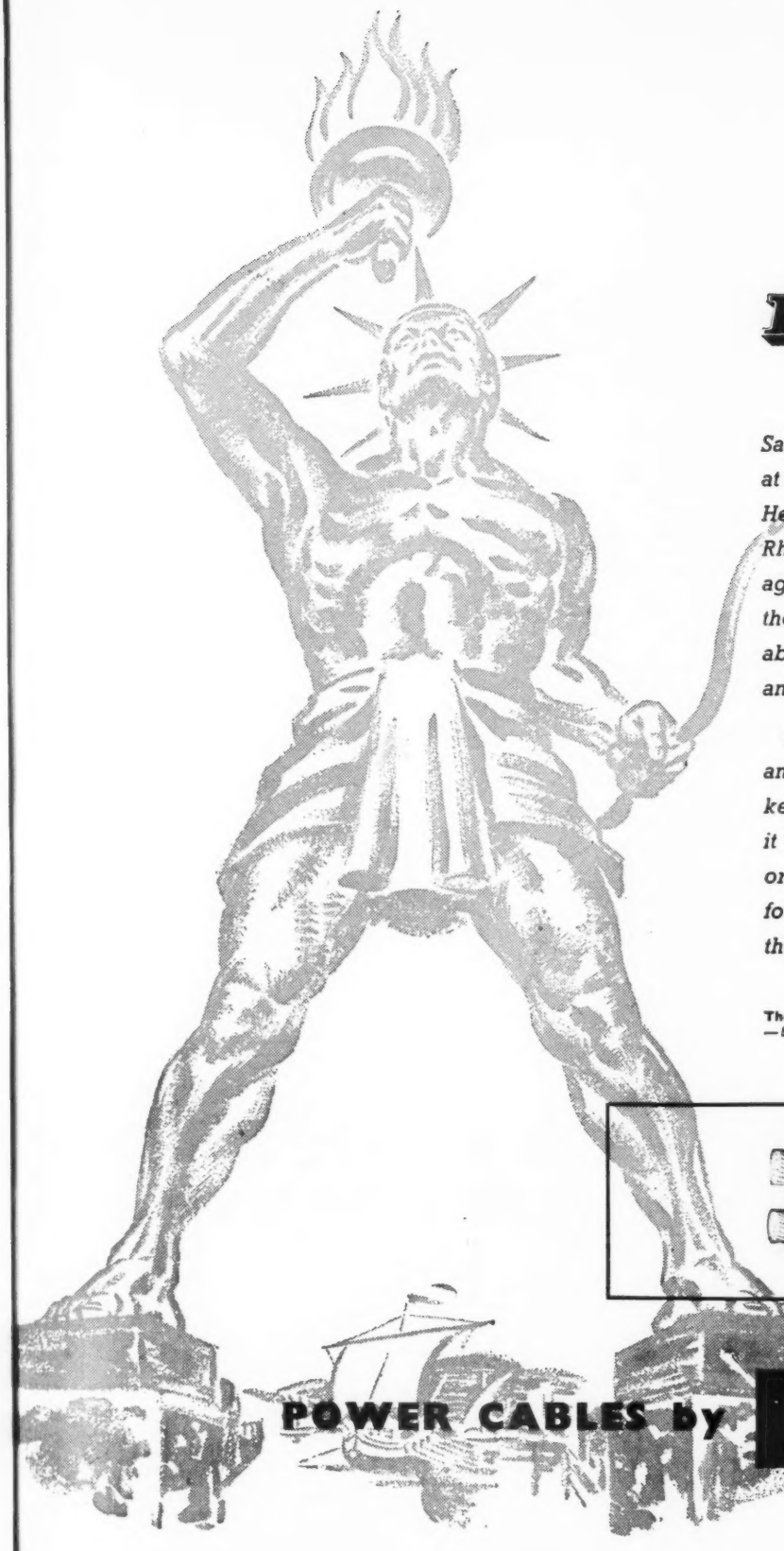

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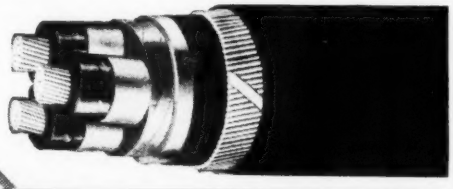

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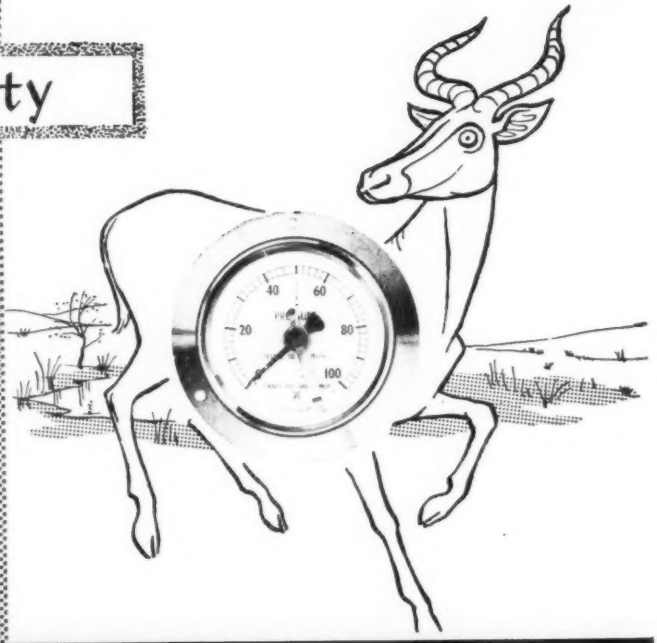

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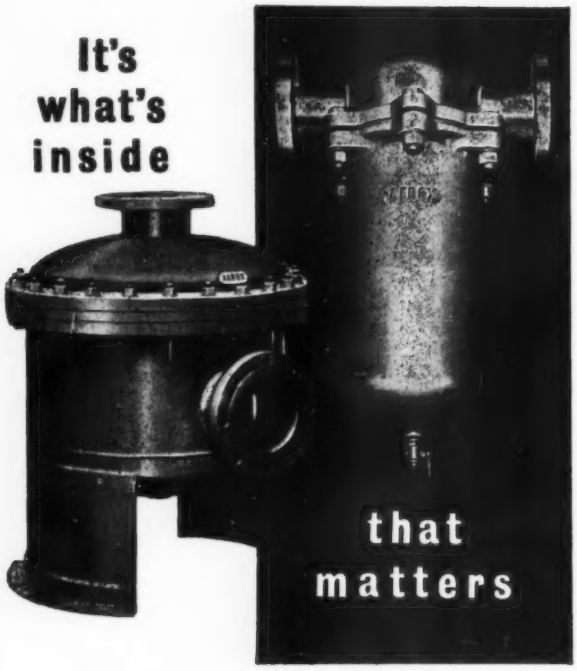

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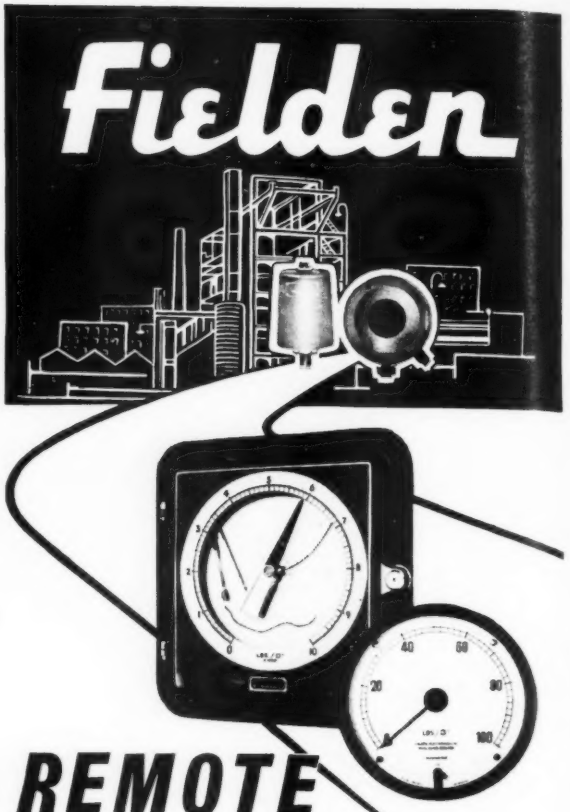

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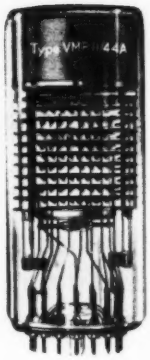

VMP 11/44A

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A new type of photomultiplier with outstanding electrical performance is now available. This tube type VMP 11/44/A is a 2" diameter photomultiplier employing an 11 stage venetian blind multiplier structure of advanced design. The tube was developed specifically to provide a photomultiplier capable of satisfying the more exacting scintillation counting applications from high resolution γ-ray spectroscopy to the counting of low energy radiation.

Three important features of this tube are high cathode sensitivity, high collection efficiency and the low inherent tube noise of the multiplier structure. The tube is particularly suited for gamma and X-ray spectrometry over a wide energy range extending to 3 KeV with a good energy resolution. In the counting of Tritium with the VMP 11/44/A employed in a refrigerated single channel counting system at –20°C, counting efficiencies of between 10 and 20% are obtained at a background of 1–2 counts per second.

In the same series the VMP 11/44/B (CV. 2316) is available for general scintillation counting applications.

For alpha scintillation counting, the VMP 11/44/C is available.

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VMP 11/44/B (CV.2316)	S11	50	200	1200	0.03	50	£30	Scintillation counting
VMP 11/44/S	S9	30	200	1200	0.003	50	£30	Low energy counting
VMP 11/44/C (CV.2317)	S11	20	20	1500	0.05	50	£15	Alpha particle monitors

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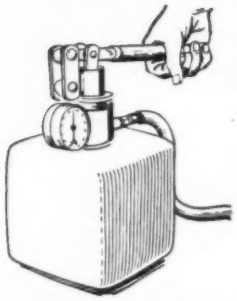

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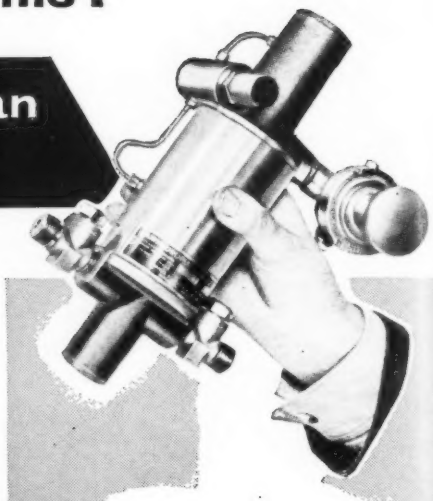

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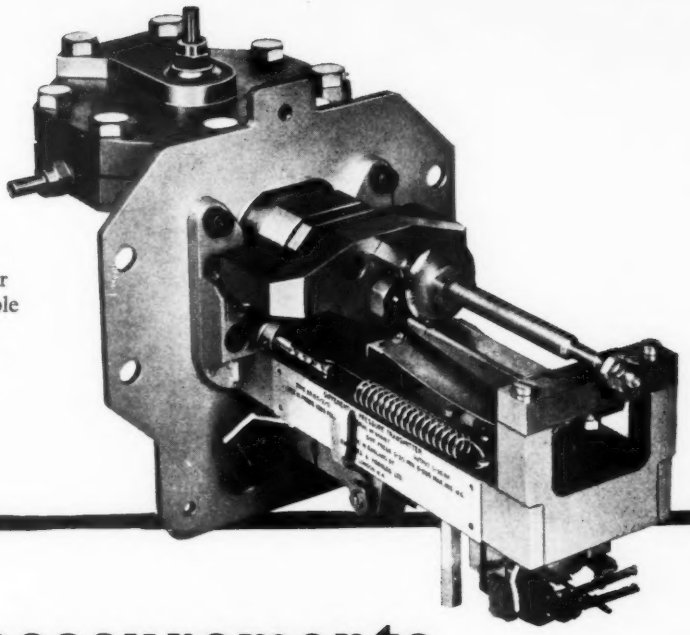

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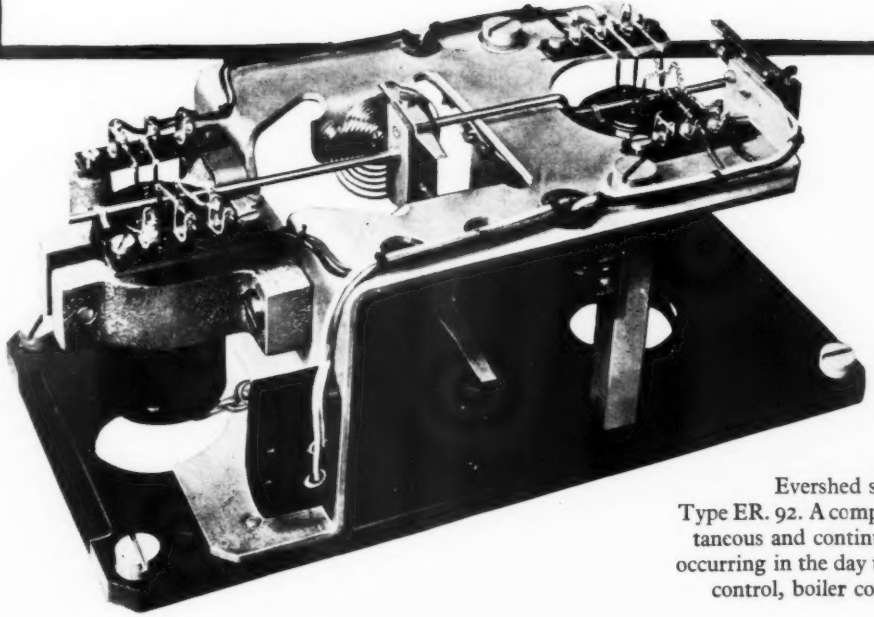

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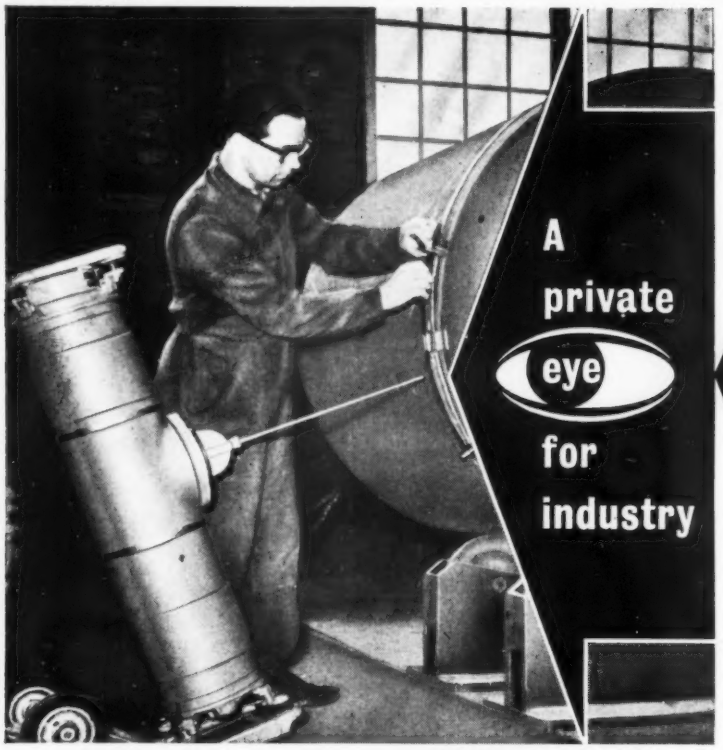

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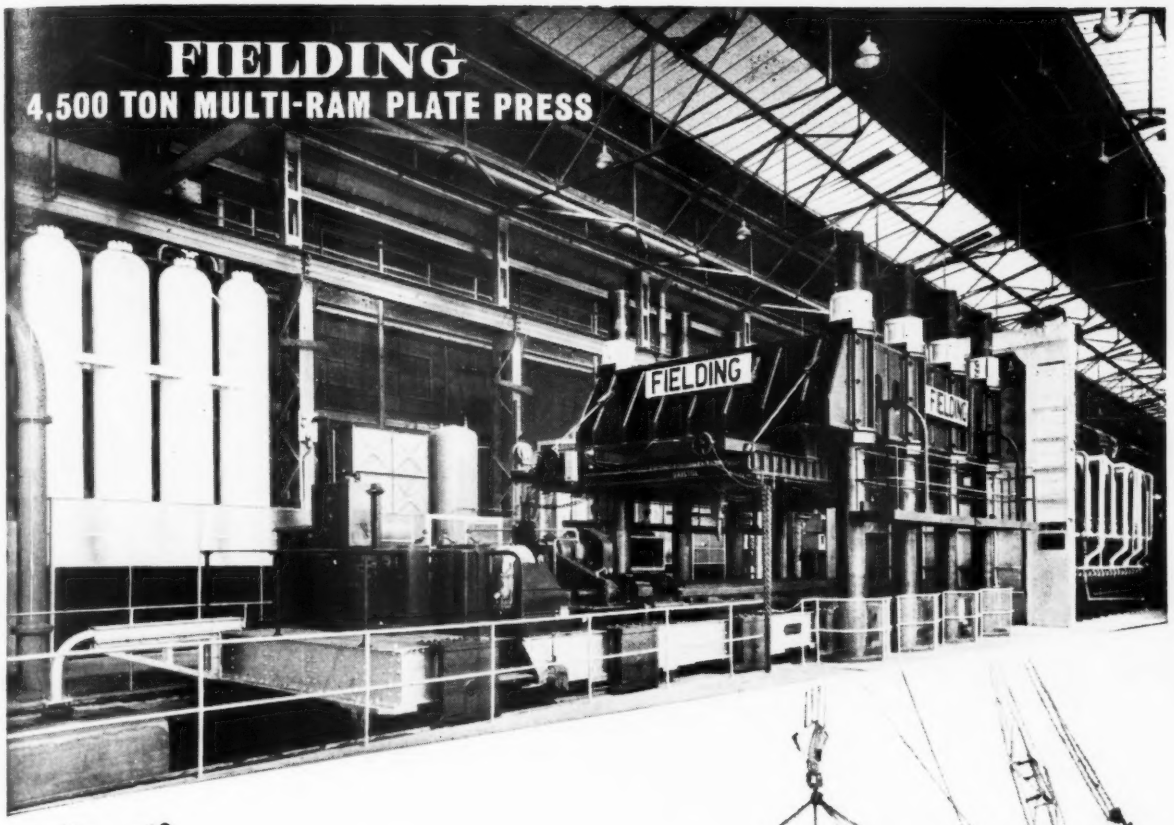

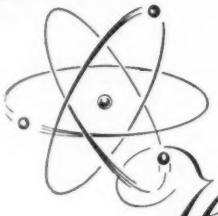

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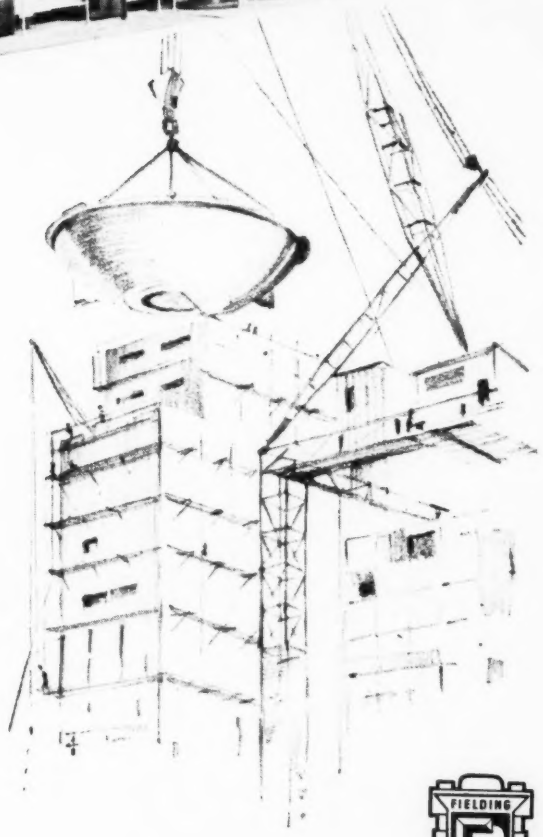

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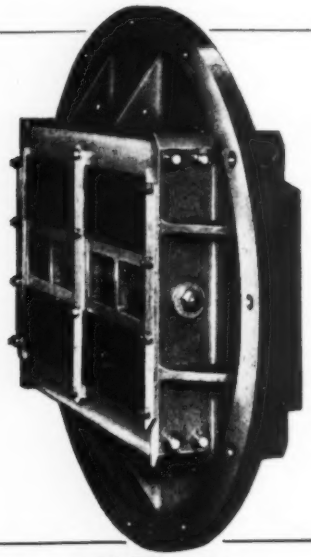

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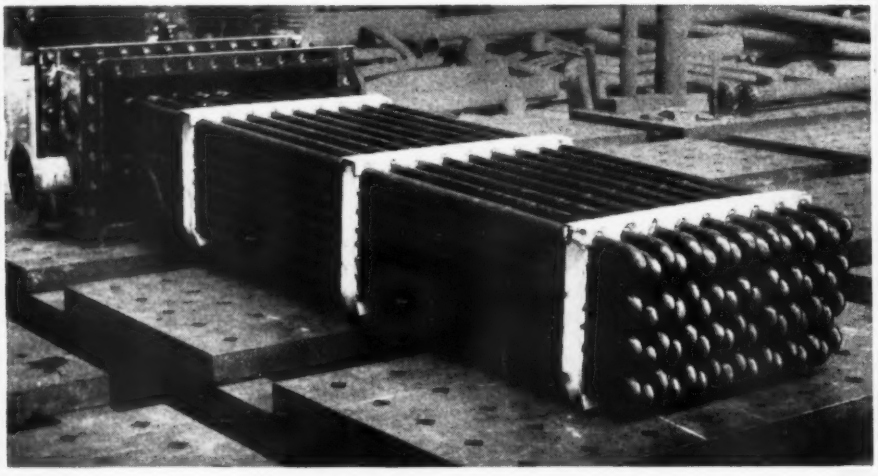

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Output : Designed to feed into 100 ohm matched cable.
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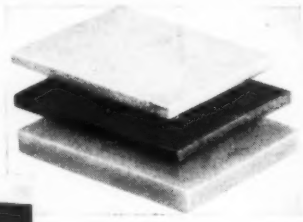

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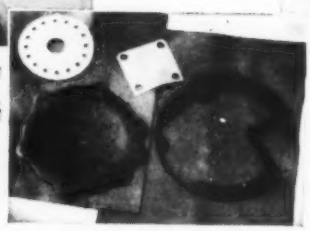

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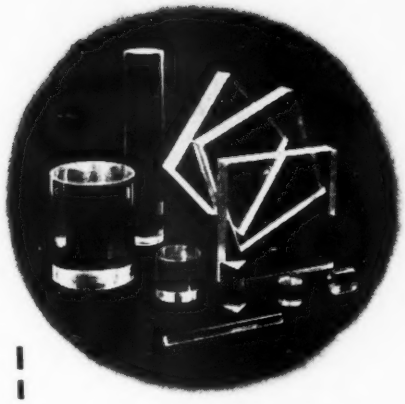

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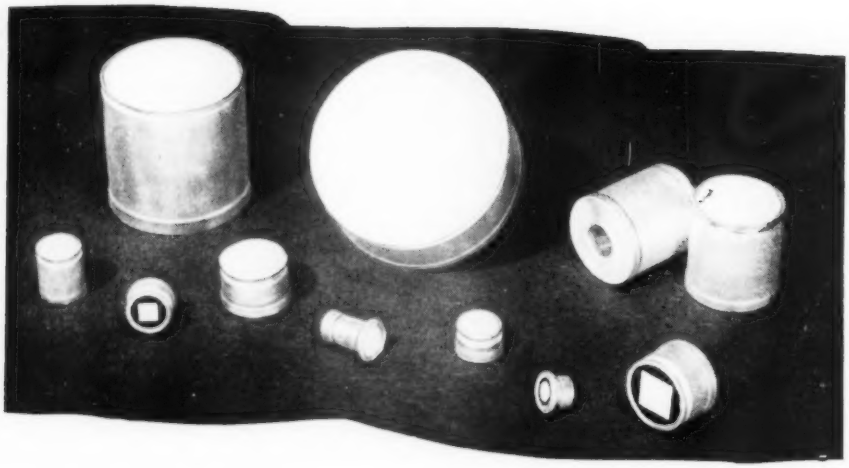

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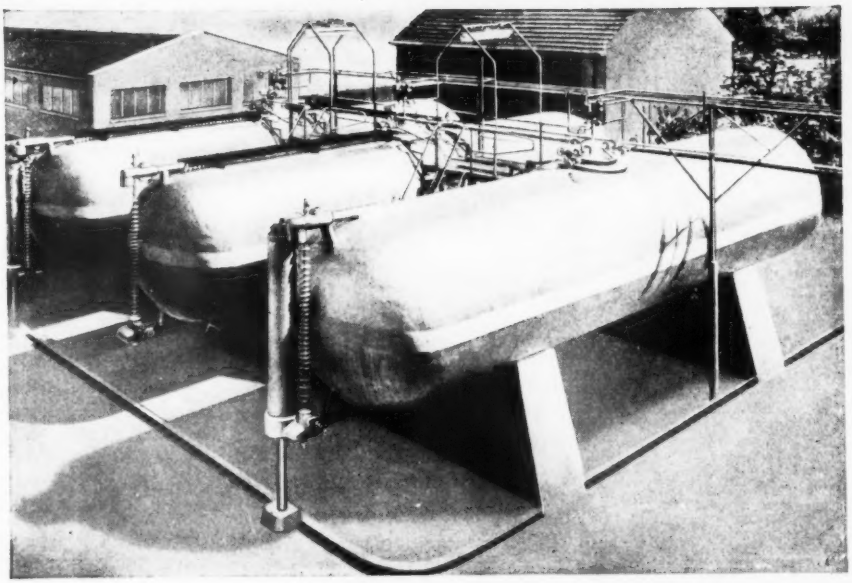

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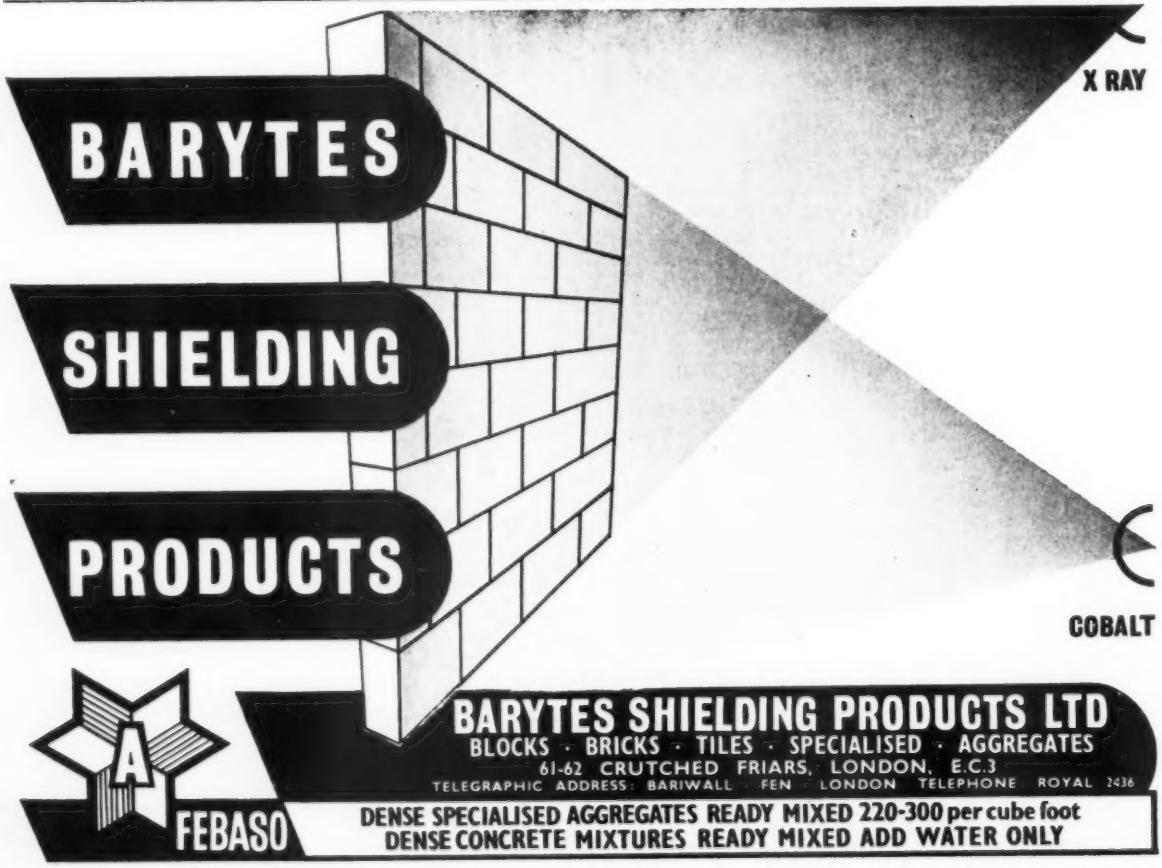

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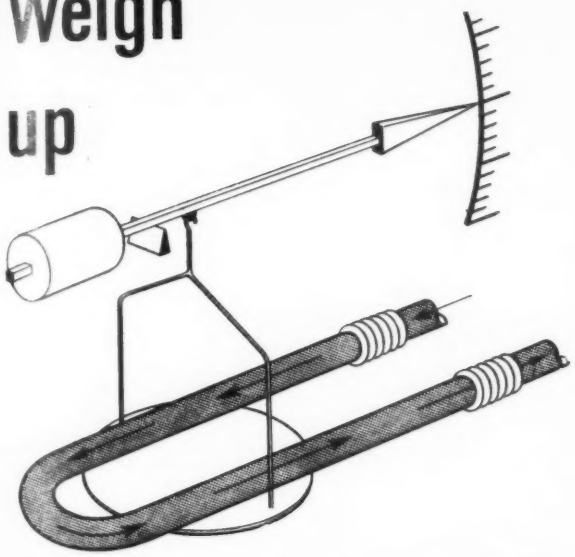
Weigh up



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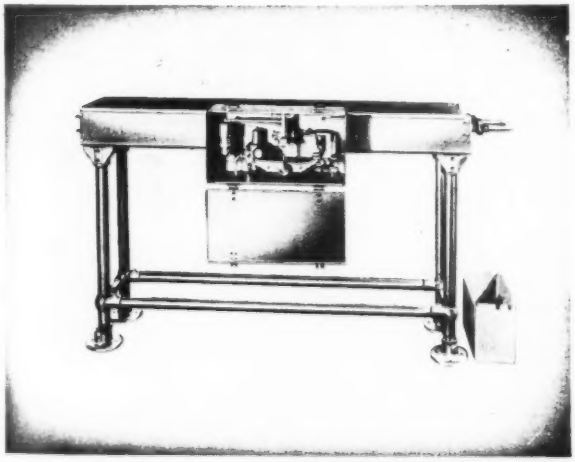

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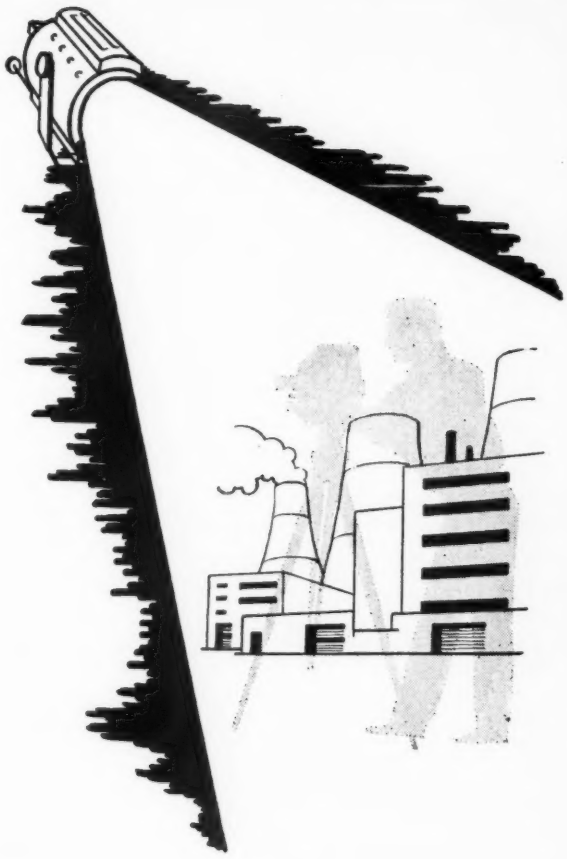

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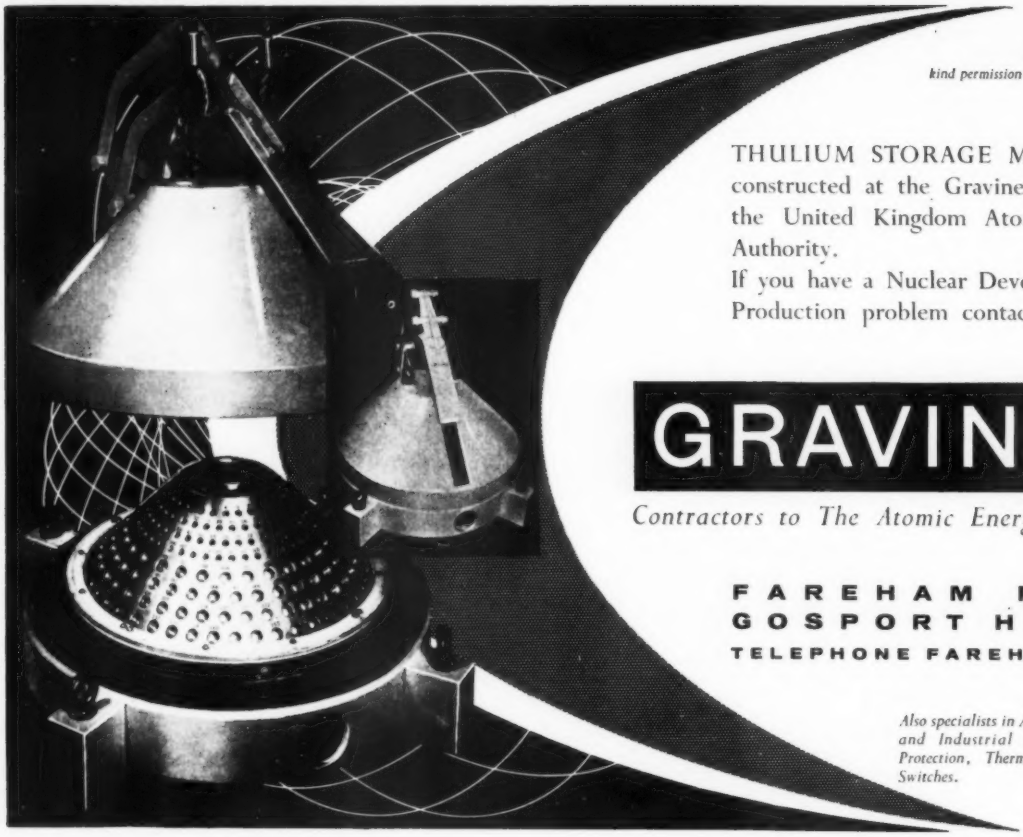

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Contractors to The Atomic Energy Authority

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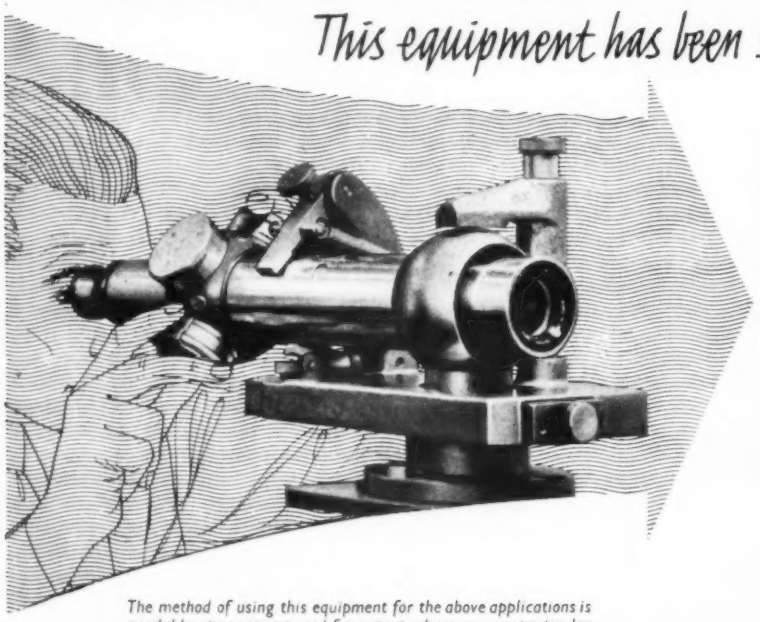
Also specialists in Airborne, Diesel Engine and Industrial Fire and Explosion Protection, Thermostats and Overheat Switches.

'MICRO' ALIGNMENT TELESCOPE

This equipment has been successfully used by . . .



. . . the United Kingdom Atomic Engineering Research Establishment in the construction of Experimental Nuclear Reactors and the associated Projects ZETA, BEPO, ZEUS, ZEPHYR, DIDO and PLUTO. Also used by the leading manufacturing groups in the construction of Nuclear Power Stations of the Power Supply Plan in Great Britain.

Sets and checks **ALIGNMENT PARALLELISM·SQUARENESS** *and* **PLANE SURFACES**

The method of using this equipment for the above applications is available upon request, and for expert advice on your particular problem, please apply to Optical Tooling Engineers' Dept.

A Division of RANK PRECISION INDUSTRIES LTD.

TAYLOR-HOBSON

TAYLOR, TAYLOR & HOBSON, LEICESTER, England.

AT 2

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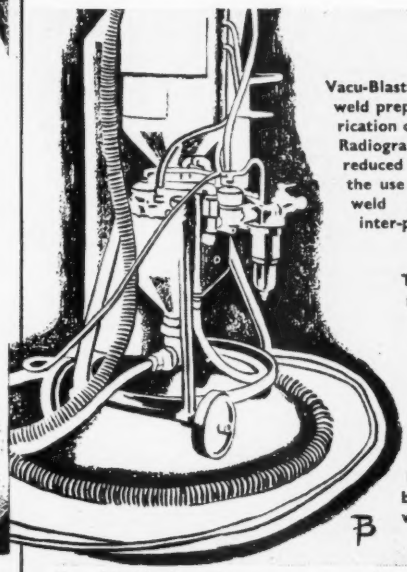
VACU-BLAST is the pre-requisite of all good welding



Vacu-Blast is unequalled for weld preparation in the fabrication of pressure vessels. Radiographic rejects can be reduced considerably by the use of Vacu-Blast for weld preparation and inter-pass deslagging.

The critical requirements imposed by Class I welding specifications necessitate the use of this mobile, dust free, grit blasting process.

Demonstrations can be arranged at your works.

Vacu-blast is the system to ensure complete recovery of abrasive

VACU-BLAST LTD., WELLCROFT ROAD, SLOUGH, BUCKS. *Phone: SLOUGH 24507/9*

Electropower Gears Ltd

KINGSBURY WORKS, KINGSBURY ROAD, LONDON, N.W.9

Telephone: COLindale 4621 (4 lines) Telegrams: LEKTROPOWA, HYDE, LONDON

★ *Hell, Nr. Trondheim, Norway.*

★ *Hammersvest, the most northerly town in the world.*

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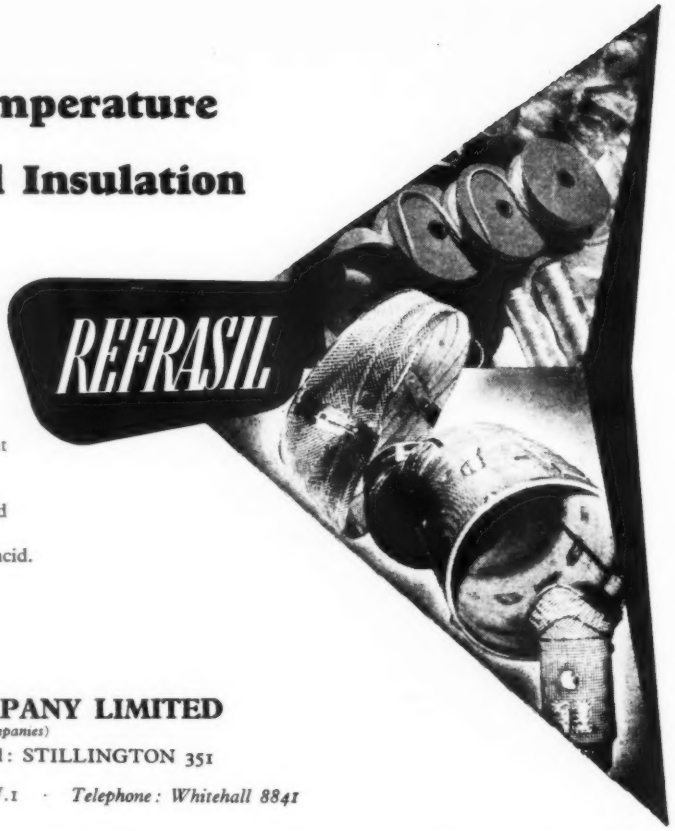
Lightweight **High Temperature**

Thermal & Electrical Insulation

REFRASIL is a unique material—
a vitreous silica fibre, light in weight,
of very fine diameter, and
capable of withstanding continuously
temperatures up to 1,000°C
(and even higher for short periods).
REFRASIL has outstanding thermal
insulating characteristics at high
temperatures, as well as being an excellent
high temperature electrical insulator.
It is available as batt, cloth, tape,
sleeving, bulk fibre, yarn or metal-covered
blankets. It is highly-resistant to
thermal shock and chemical attack from acid.



For further details about Refrasil please write to—

THE BRITISH REFRASIL COMPANY LIMITED
(A member of the Darlington Group of Companies)
STILLINGTON, COUNTY DURHAM · Tel: STILLINGTON 351
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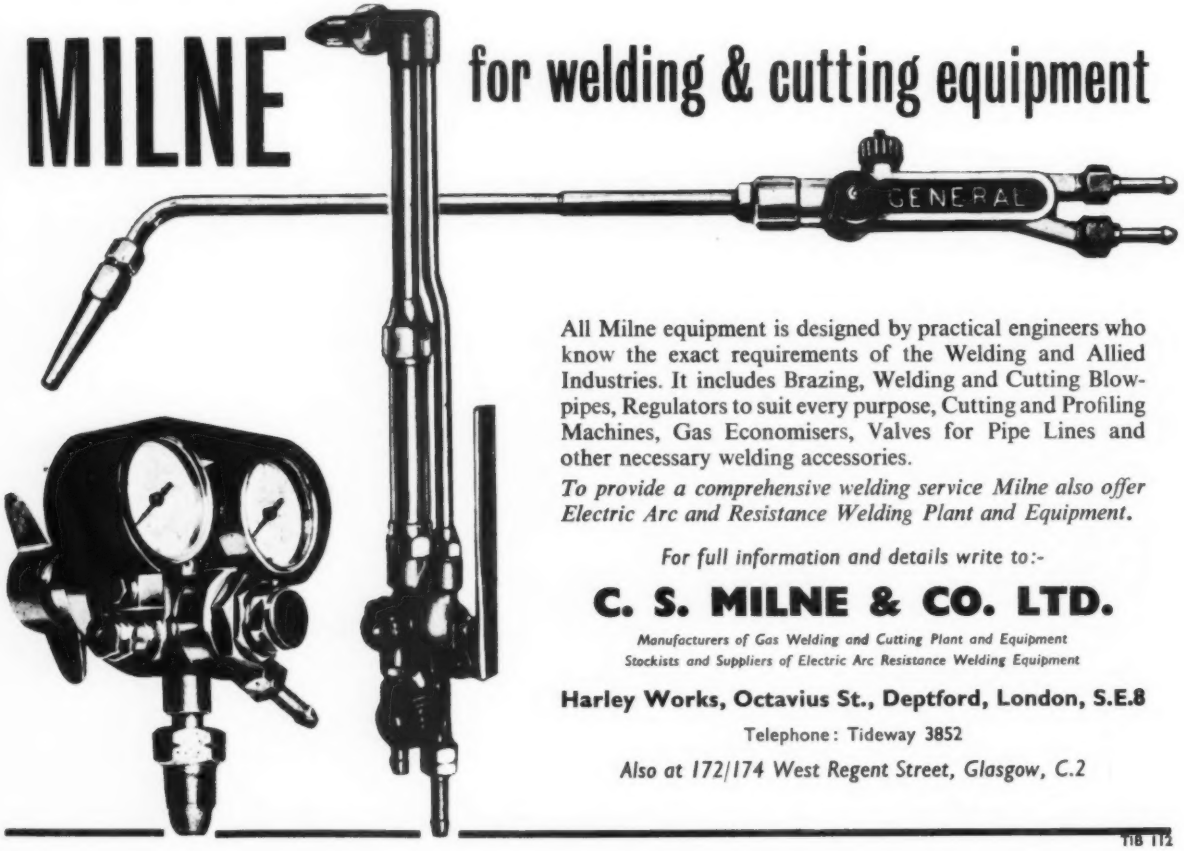
MILNE for welding & cutting equipment



All Milne equipment is designed by practical engineers who know the exact requirements of the Welding and Allied Industries. It includes Brazing, Welding and Cutting Blowpipes, Regulators to suit every purpose, Cutting and Profiling Machines, Gas Economisers, Valves for Pipe Lines and other necessary welding accessories.

To provide a comprehensive welding service Milne also offer Electric Arc and Resistance Welding Plant and Equipment.

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C. S. MILNE & CO. LTD.

Manufacturers of Gas Welding and Cutting Plant and Equipment
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Harley Works, Octavius St., Deptford, London, S.E.8

Telephone: Tideway 3852

Also at 172/174 West Regent Street, Glasgow, C.2

TIB 112

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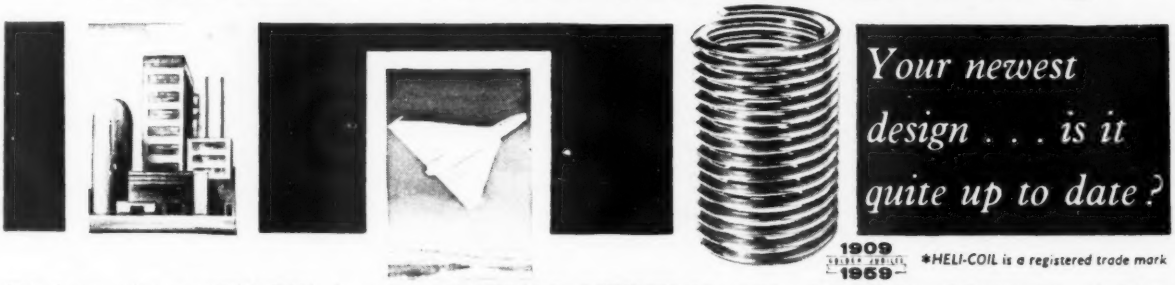
the embodiment of this scientific age

Forward-looking engineers are embodying Heli-Coil Screw Thread Inserts in their designs because competition demands that they use only today's most advanced and successful techniques.

The Heli-Coil method of screw thread engineering can improve products in almost an infinity of ways. It can make dramatic cuts in time and labour costs.

The Heli-Coil Insert is ideal for automation. Why not have all the information in front of you—ask for Sales Leaflet APL 48/E 13

HELI-COIL*
SCREW THREAD INSERTS



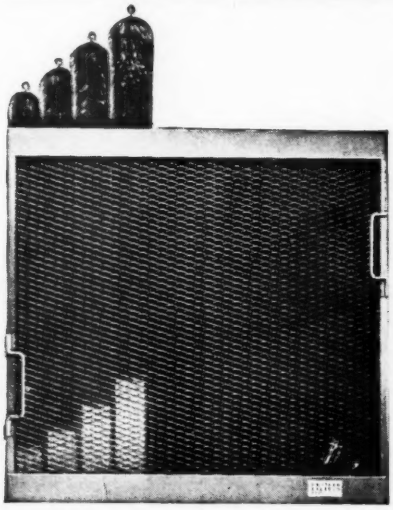
*HELI-COIL is a registered trade mark

Write for more data on HELI-COIL inserts to **ARMSTRONG PATENTS CO. LTD. EASTGATE, BEVERLEY, YORKS.**

Tel: Beverley 82212 (6 lines)

YOU DON'T NEED SPECIAL EQUIPMENT OR FLUIDS TO CLEAN THIS AIR FILTER!

Heather Multi-Brush Air Filters can be cleaned easily and thoroughly, without special equipment or fluids, and still retain the initial filtering efficiency. In fact, maximum efficiency and minimum maintenance is the correct way to sum up this unique, low-cost filter system.



A finely graded mesh of intermingling hair, specially selected to withstand the varying humidity and conditions of the dust-laden air, is used to trap impurities and dust particles from the incoming air stream. Periodically, the filter brushes can be cleaned simply by shaking or suction cleaning.

Write NOW for leaflet H39 which gives full details.

HEATHER FILTERS LIMITED

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HF.42

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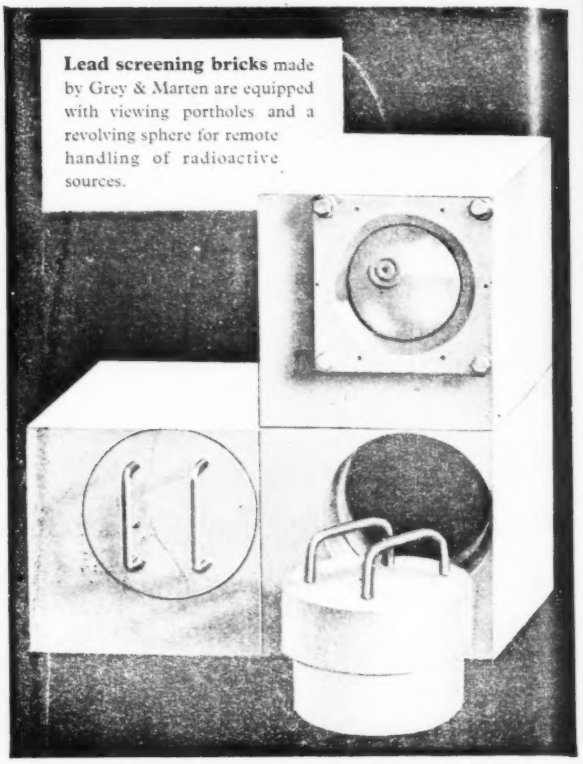

Lead screening bricks made by Grey & Marten are equipped with viewing portholes and a revolving sphere for remote handling of radioactive sources.

Ask Grey & Marten about lead shielding

(Their new subsidiary, James Girdler & Co., has all their skill and experience)

GREY & MARTEN are experts in lead. They've specialised in the manufacture of *all* kinds of lead castings, fabrications and fillings for more than a century. Interlocking Lead Bricks (in one, two and four-inch thicknesses), Lead Sphere Units (in two and four-inch bricks), Aperture and Viewing Bricks, Lead Pots and Isotope Carriers are all produced under the Grey & Marten name. Now they have handed over this activity to their new subsidiary, James Girdler & Co. Ltd.

Storage pot typical of those used in standard safes not already fitted with lead protection, affords economical storage for radio-active material.

GREY & MARTEN LTD

Established 1833

CITY LEAD WORKS, SOUTHWARK BRIDGE, S.E.1
and at Birmingham, Manchester and Ipswich

JAMES GIRDLER & CO. LTD

Mansell Works, Mansell Road, London W.3 CHISWICK 5991

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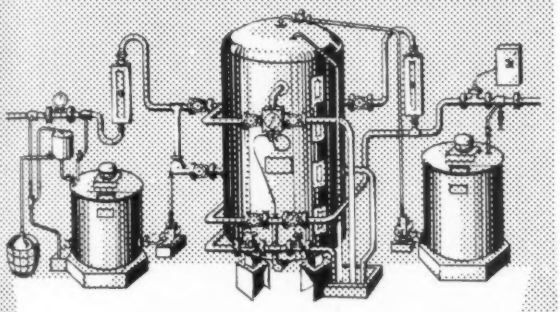
PURE WATER

for Industrial purposes



ION EXCHANGE

is the most up-to-date method of producing pure water for all requirements, and it does this at a fraction of the cost of distillation.

Literature, describing the full range of Ion Exchange processes and plants, available on application.

NECKAR

NECKAR WATER SOFTENER CO. LTD.
Artillery House · Artillery Row · London, S.W.1.

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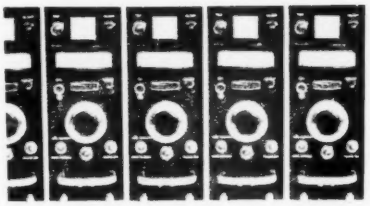
murphy



TRIP AMPLIFIERS

for monitoring

TEMPERATURE, STRAIN,
and any low level d.c. signal.

Some salient features:

Transistorised high-speeed chopper amplifier.

Relays and lamps operate at alarm and trip levels.

Trip margin indication with two scales at 10:1 sensitivity ratio.

Lockable pre-set trip level control calibrated 0 — 1000.

Rejects extraneous 50 c.p.s pick-up.

Incorporates all possible fail-safe techniques.

Compact size, $8\frac{3}{4}'' \times 3\frac{1}{2}'' \times 13''$ *deep allows 5 units per standard 19" rack.*

For further information please contact:

MURPHY RADIO LTD (ELECTRONICS DIVISION)
WELWYN GARDEN CITY, HERTFORDSHIRE.
TEL. No. WELWYN GARDEN 3434.

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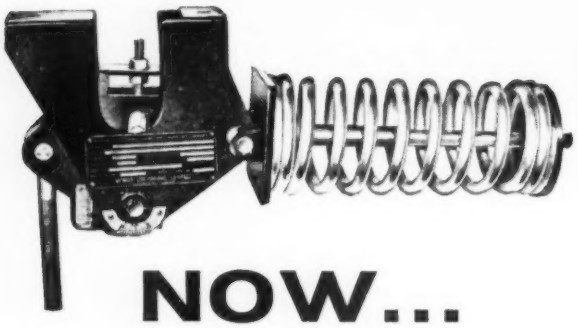
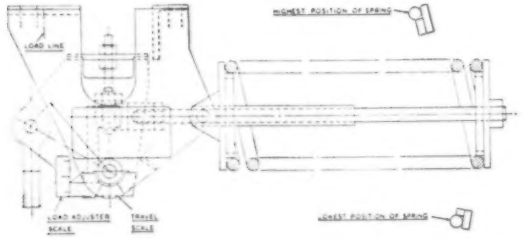


NOW...

'M' range Gensprings up to 80,000 lbs. and 12" travel ... only 2% deviation

Our new 'M' range of Constant Support Hangers is now available for loadings up to 80,000 lbs. and 12" travel—down to 2% deviation. More economical, both in application and first cost, and more compact than previous types, they provide increased travel with less headroom requirement. The 'M' Hangers have been developed from the 'W' range which have been chosen for Britain's first three commercial nuclear power stations.



At Bradwell, Berkeley, and Hunterston, Gensprings will provide safe, secure support of vital piping installations. The Constant and Variable Gensprings, together with the Sway Brace, provide a fully comprehensive range for all pipe support requirements and are, of course, widely used in conventional power stations, oil refineries, chemical plants, etc.

If you would like to know more about the new 'M' range, please send for full details.

Vokes Genspring

SUSPENSION SYSTEMS

VOKES GENSPRING LTD · GUILDFORD · SURREY

VG.24

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UNION CARBIDE TRADE MARK

RARER METALS...

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UNION CARBIDE can now supply a number of the rarer metals, many of which are available in a very high purity grade

...AND THEIR COMPOUNDS

Over 70 compounds of the rarer metals are available and include oxides, nitrides, borides, carbides, chlorides, phosphides, sulphides, phosphates, selenides, acetylacetonates and carbonyls.

CATALOGUES OF DATA SHEETS

giving the composition and properties of the metals and compounds can be obtained on request.

UNION CARBIDE LTD. ALLOYS DIVISION
103 Mount Street, London W.1

The term 'Union Carbide' is a trade mark

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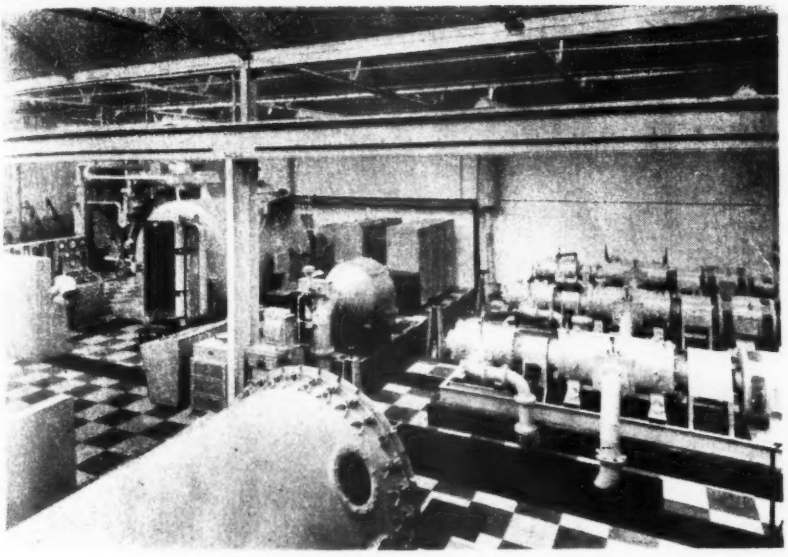


Part of the English Electric Aircraft Equipment Laboratories with three HOLLAND SLM 2-stage rotary vacuum pumps exhausting the altitude test chamber.

HOLLAND / SLM

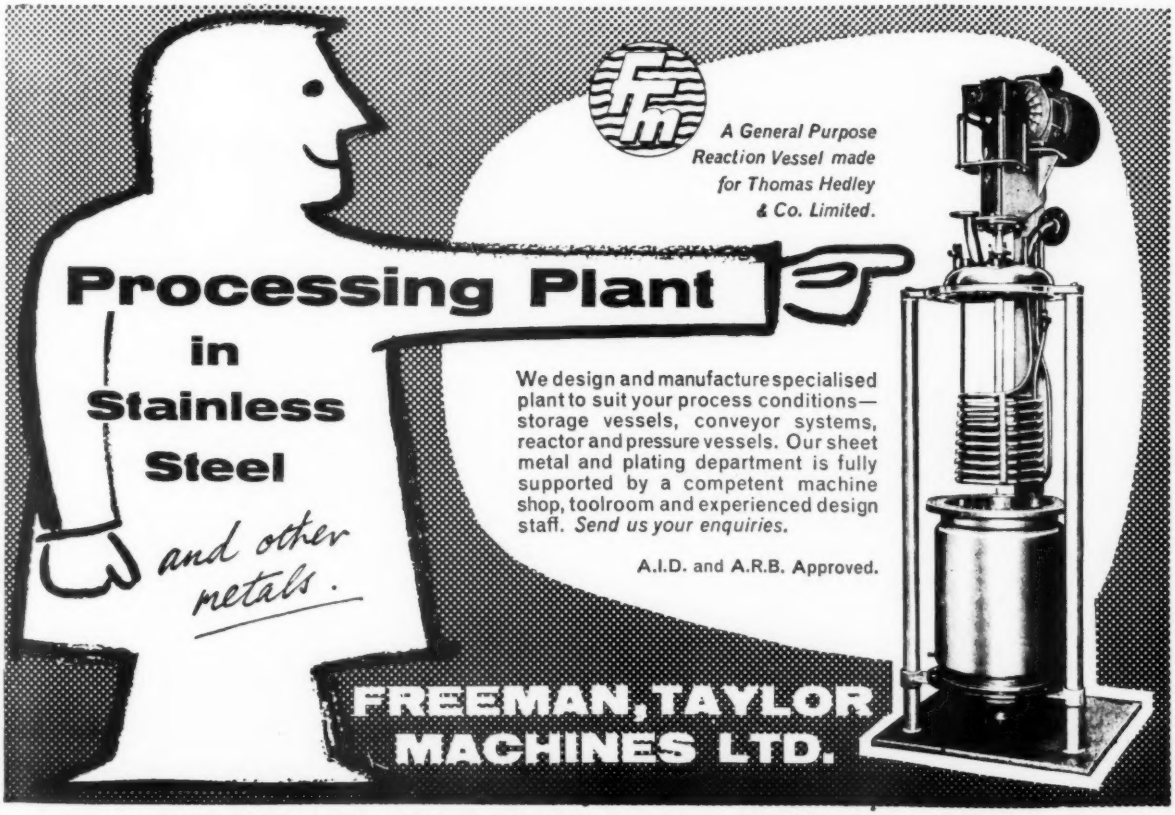
ROTARY COMPRESSORS AND VACUUM PUMPS

GIVE SERVICE FOR TO-DAY FOR TO-MORROW AND FOR YEARS AHEAD

The B. A. Holland Engineering Co. Ltd.

LINDO LODGE, STANLEY AVENUE, CHESHAM, BUCKS.

Telephone: Chesham 8406/8 Telegrams: Picturable. Chesham Works: SLOUGH, BUCKS


A General Purpose Reaction Vessel made for Thomas Hedley & Co. Limited.
Processing Plant in Stainless Steel and other metals.
We design and manufacture specialised plant to suit your process conditions—storage vessels, conveyor systems, reactor and pressure vessels. Our sheet metal and plating department is fully supported by a competent machine shop, toolroom and experienced design staff. Send us your enquiries.
A.I.D. and A.R.B. Approved.
FREEMAN, TAYLOR MACHINES LTD.

Dept. L. NECTON STREET, SYSTON, LEICESTER, ENGLAND. Phone: Syston 3301 (5 lines) Grams: 'DYEMAC' Leicester

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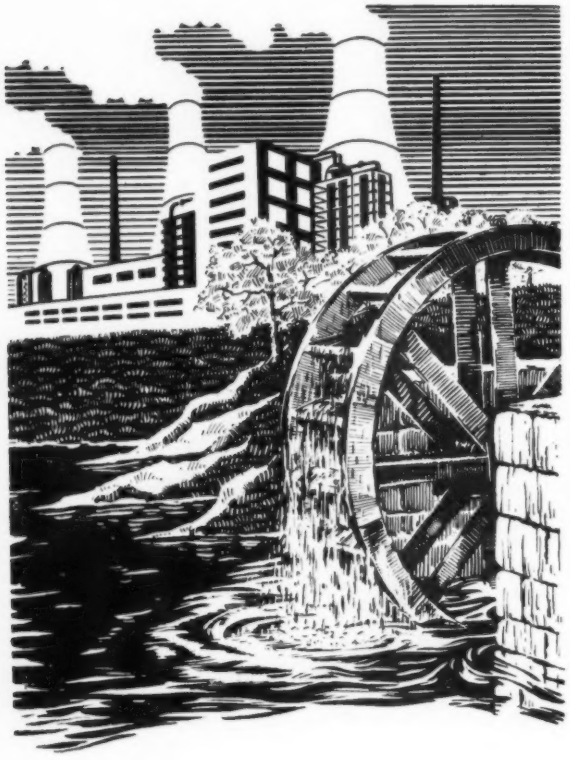

WATER

is still in the foreground...

However revolutionary the methods of producing power may become, water is still all-important; and the need to give complete and lasting internal protection to water tanks in modern plants remains paramount.

With a reputation consolidated over 30 years of successful use

BITOTES Solution and Enamel

prevents interior corrosion of all steel and concrete water containers and conduits. BITOTES cannot crack or peel and is tasteless and odourless when dry. It is fully approved for Fresh Water, Drinking Water, Demineralised Water, etc.

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BITULAC LIMITED

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London Office: 189/190 Temple Chambers, Temple Avenue, London, E.C.4

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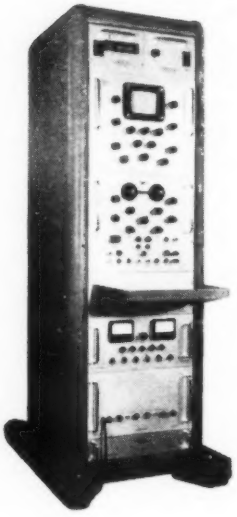
MARSHALL



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TYPE H.S.100

★ Torsional delay line data storage with computer reliability

★ Resolution constant or proportional to amplitude

★ Background subtraction

★ Analysis of pulses of either sign from 1 mV to 50 V

★ Binary and decimal storage

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★ Total count scaler and accurate live time integrator both of which are available for use as separate units

MARSHALL

TWIN-CHANNEL PULSE GENERATOR MODEL T·P·G·100

Designed as a universal instrument for the development and general testing of electronic equipment. Extreme flexibility in use is achieved by virtue of the complete independence of the two channels apart from a common repetition frequency. The output pulses are fast-rising, of clean waveform, and at low impedance level.

In addition to the facilities normally offered in a pulse generator, precise measurements of the resolution time of coincidence circuits, triggering characteristics of discriminators, and the overload performance of pulse amplifiers are readily made.

A pre-pulse is provided for the purpose of triggering auxiliary apparatus.

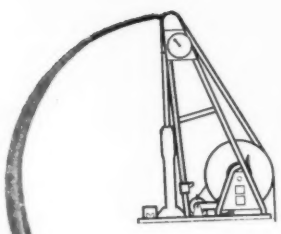
The "A" and "B" channel output pulses are independently variable in amplitude, duration, risetime, delay relative to the pre-pulse and polarity.

Pulses from the two channels may be additively mixed if desired so that they appear at a single terminal.

FOR COMPLETE DATA WRITE TO:

MARSHALL OF CAMBRIDGE ELECTRONICS LIMITED

THE AERODROME, CAMBRIDGE, ENGLAND



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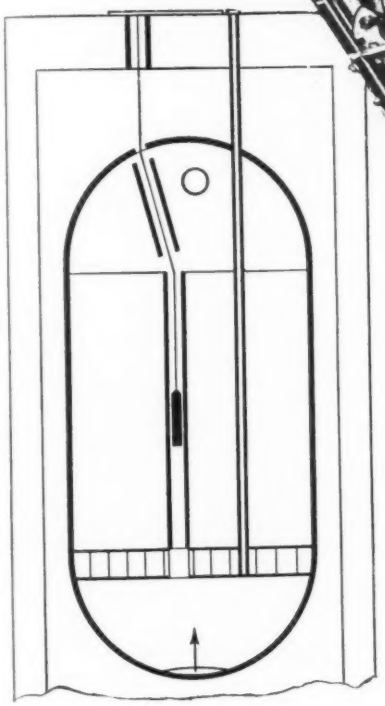
REACTOR INSPECTION
TELEVISION EQUIPMENT

REACTOR CAMERA

Television is a vital technique in the operation of gas-cooled reactors. The type of camera shown is in regular use at Calder Hall Nuclear Power Station, England; it carries its own lighting, and in addition to visual inspection of the reactor interior, permits the removal of objects from the reactor using the special grab attachments. All the camera facilities are controlled remotely.

The camera functions satisfactorily with radiation dose rates greater than 10^5 Rads. per hour; cooling gas, carried to the camera by the supporting hose, allows operation with ambient temperature of 150°C.

Direct experience of such conditions over a number of years has enabled Pye to design cameras that will withstand high levels of nuclear radiation, temperature and pressure. Models can be supplied for use in water-cooled reactors. If you have any specialised television requirements, contact Pye Ltd., and avail yourself of their experience.



This console gives complete remote control of the camera. It carries the picture monitor and the control unit.

PYE LIMITED · ATOMICS DIVISION · CAMBRIDGE ENGLAND

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Illustrated is the twin cylinder model having a free air delivery of 50 c.f.m.

W&J OIL FREE COMPRESSORS

DISPLACEMENT RANGE 1 to 136 c.f.m.

In the Food Processing, Brewing, Chemical and Paper Industries, also for pneumatic instrument control, it is essential that the air is free from oil in both droplet or vapour form. The W&J compressors use carbon rings and completely dry cylinders to achieve this purpose.

Manufactured now for several years they have proved themselves successful in many industries.

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GLOUCESTER · ENGLAND
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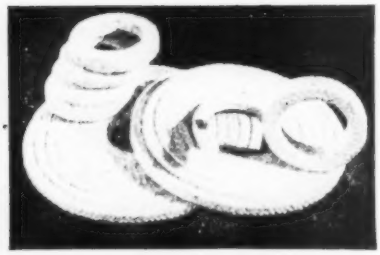
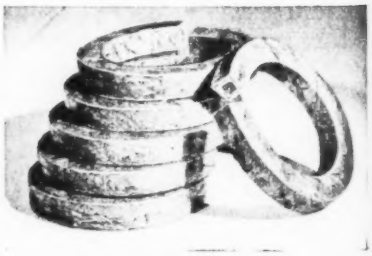


WHITE BELDAMOK
The specially developed graphite-free packing for superheated steam at temperatures up to 1100 F.

BELDAMOK
The high grade asbestos packing lubricated for general high-temperature service up to 650 F.



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A range of metal foil packings combining low friction with good resilience and designed for high speed rotating shafts.

Telephone or write for your copy of the LASCAR Manual—the best guide to better service in the application of jointings and packings.

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BELDAM ASBESTOS COMPANY LIMITED · LASCAR WORKS
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Il est souvent difficile au client publicitaire d'indiquer dans un espace restreint tous les détails de ses produits. Dans le cas où vous désireriez de plus amples renseignements à ce sujet, veuillez pointer le numéro approprié sur la carte ci-contre et envoyer cette dernière à NUCLEAR POWER.

AUSKUNFTSDIENST FÜR LESER

Es ist oft schwierig für Inserenten alle technischen Einzelheiten über ihre Produkte in einem begrenzten Platz zu bringen. Sollten Sie noch weitere Auskünfte wünschen, streichen Sie einfach die bestimmten Nummern auf der nebenstehenden Karte an, und senden Sie sie an NUCLEAR POWER.

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在廣告上以有限的地方來解釋一些專門技術 及它們的功示 的確是有受限制的困难若欲要求知道一些詳細的情形就請將对頁的表格 取一號下來附圈下有疑问的項目 问笔勾一寄到本社就可。

讀者サービス

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Nuclear Power
REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · IRRADIATION

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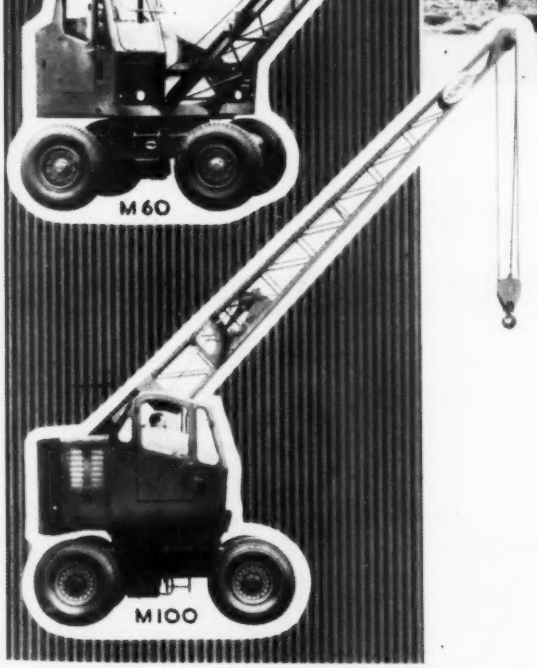

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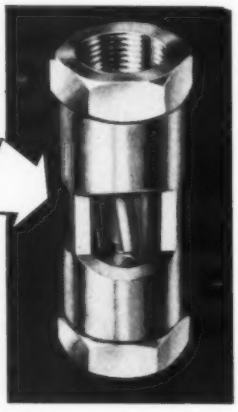

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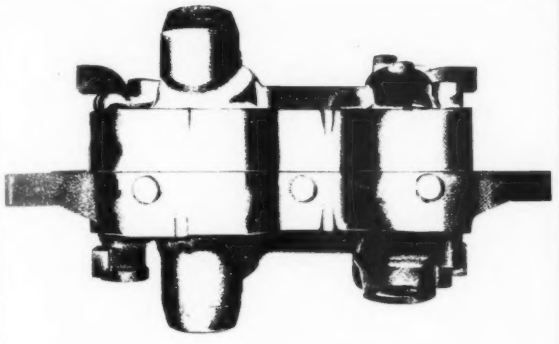

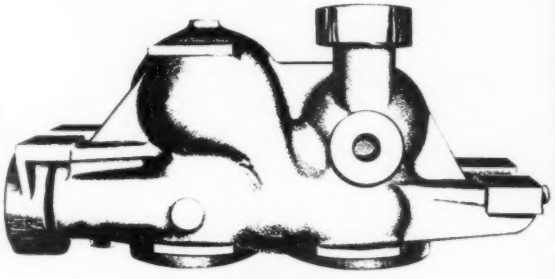

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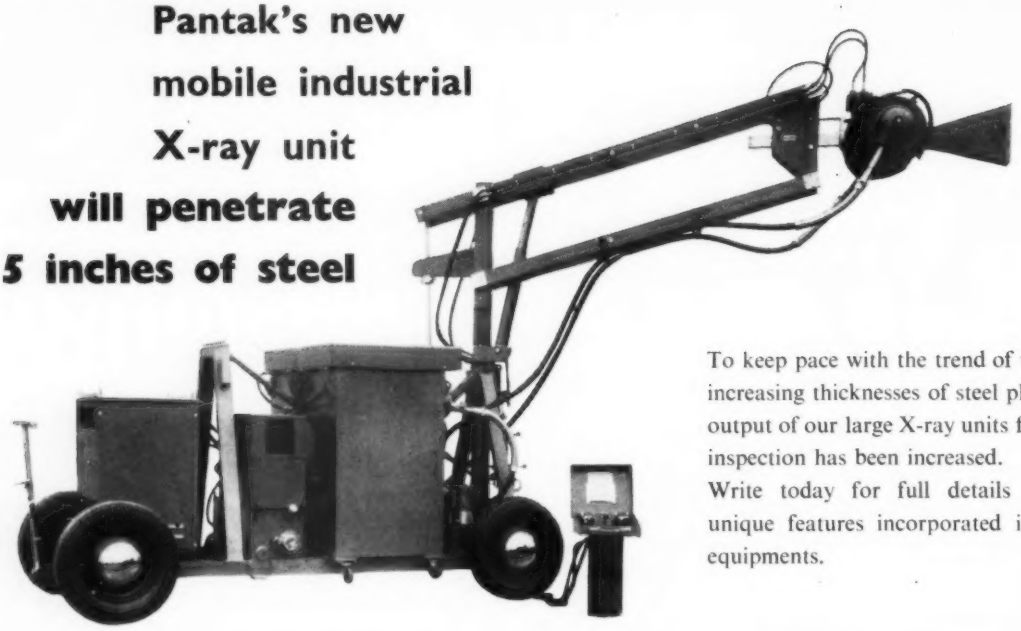

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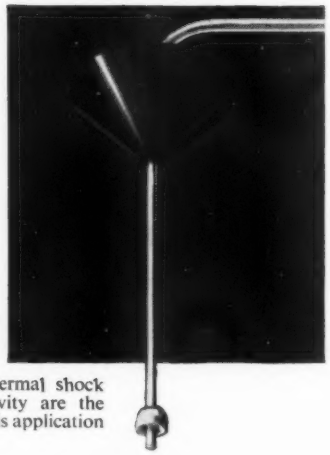

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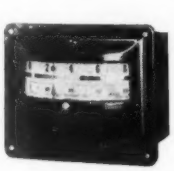

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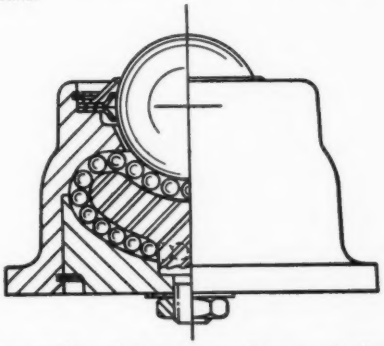

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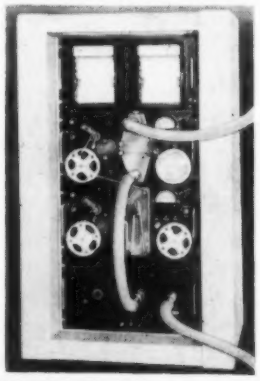

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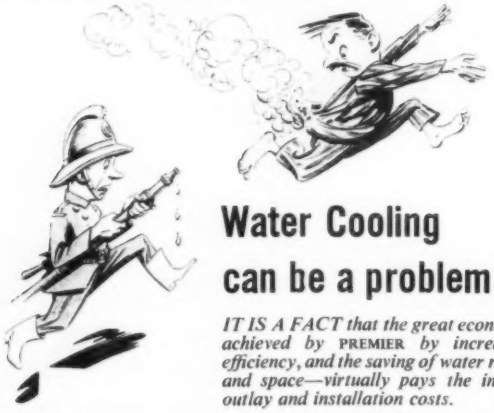

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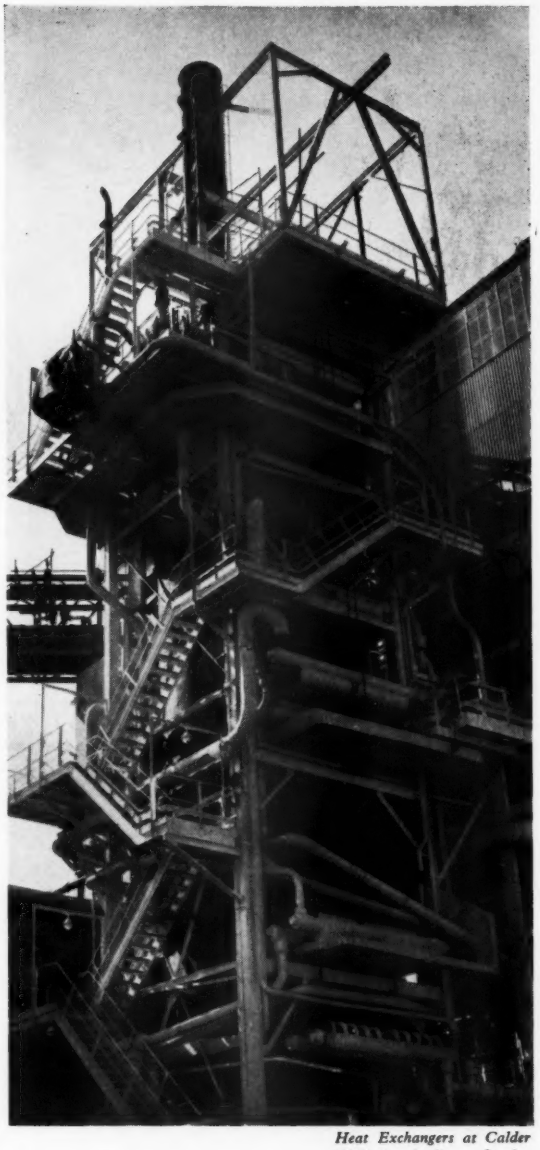

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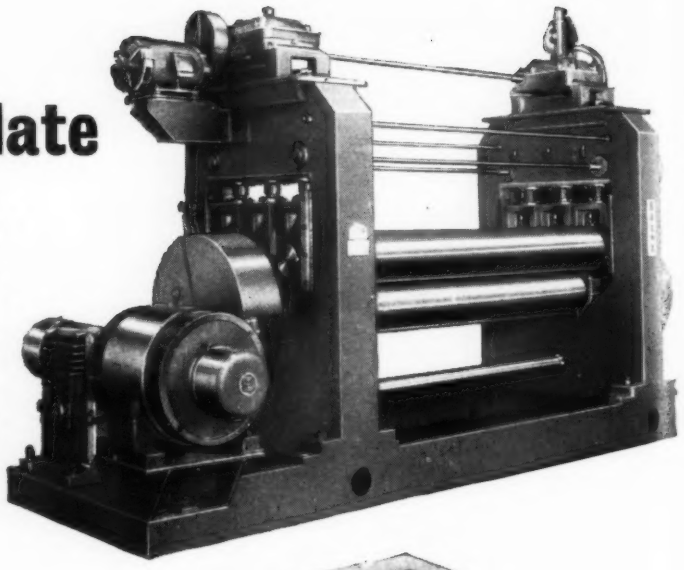

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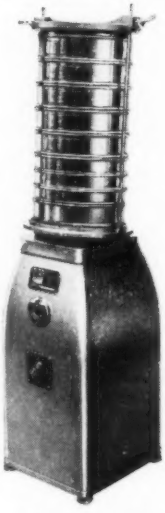

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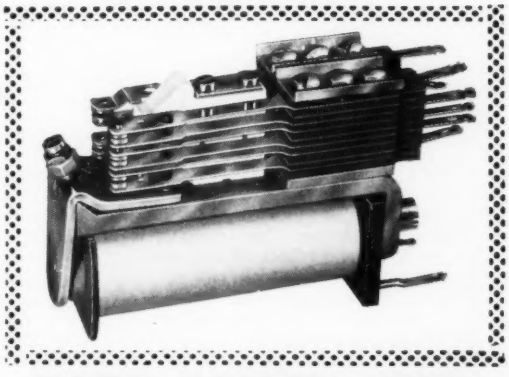

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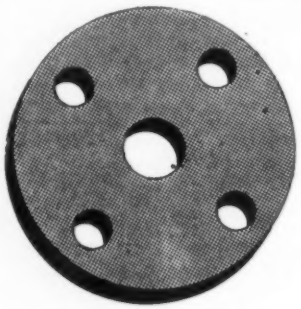

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